A

GEOLOGICAL INQUIRY

RESPECTING

THE WATER-BEARING STRATA

OF THE COUNTRY

AROUND LONDON,

WITH REFERENCE ESPECIALLY TO

THE WATER-SUPPLY OF THE METROPOLIS;

AND INCLUDING SOME REMARKS ON SPRINGS.

BY

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I.—INTRODUCTORY OBSERVATIONS.

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§ 1. *Object of the work.—General view of the subject.*

1. The attention of the author was first directed to the subject of the present work by the apparent want of sufficient geological information bearing upon the question of "Artesian wells," and by the uncertainty as to their capabilities and value, which seemed to prevail in the discussions of the many plans brought forward in the course of the last few years, for the better supply of water to the metropolis.

Some acquaintance with the Geology of the district, which had led incidentally to an examination of the Artesian wells, joined to the general interest of the subject, was the cause of his engaging in this inquiry; not, however, with any purpose of treating it in that detail which the special nature of the subject would require, but rather with the hope of calling attention to the practical application of Geology in an important economical question, and of establishing some general principles which may serve to guide to further and more exact investigations.

Although since the commencement of this work the several districts have been visited by the author with reference more especially to the object he has had in view, the greater part of the observations recorded in the following pages are the

result of inquiries originally directed to questions of pure Geology in connection with the age and relations of the Tertiary strata around London; and having been made without any anticipation of their present application, there are many points which are not entered upon so fully as otherwise they might have been. But still it is hoped that the general details which are given of the physical Geology of the district may prove of some utility, and that they may direct attention to the probability of obtaining at London, by means of a fresh system of deeper Artesian wells, a very much larger and better supply of water than that furnished by those which exist at present.*

2. The limpidity and freedom from organic impurities of the deep well water in the London Tertiary district,† and its

* It would be difficult to account for the generally unfavourable opinion entertained regarding Artesian wells as a means of public supply, were it not that the annually decreasing yield of water from the Tertiary sands, and the chalk, beneath London, has produced an impression of uncertainty as to all such sources of supply; which, with the constantly increasing expense caused by the depth from which the water has to be pumped, and the proportion of saline ingredients being so much greater in these than in the river waters, have been taken as sufficient grounds of objection. But it is to be observed, in explanation of the diminished supply from the present sources, that the Tertiary sands are of very limited dimensions, that the chalk is not a freely permeable deposit, and that the peculiarities of the saline ingredients depend upon the chemical composition of these formations. All these causes, however, are local, and can by no means be considered as grounds of objection against the system of Artesian wells generally.

† For various opinions with regard both to quality and quantity, see,—Dr. Buckland's Bridgewater Treatise, p. 564,—Prof. Brande, in the Journal of the Chemical Society, Vol. II. p. 345,—Prof. Graham, in the Memoirs of the Chemical Society, Vol. II. p. 239,—Messrs. Abel and Rowney, in Reports of the Royal College of Chemistry, Vol. I. p. 33,—Report of the Board of Health on the Water Supply to the Metropolis, and Mr. Homersham's review of the same,—Report of a Lecture delivered by Dr. Buckland at the Royal Institute of British Architects, in Nov. 1849, and published in their "Proceedings,"—Remarks on the Water Supply of London, by Sir W. Clay, p. 39,—Letters of Mr. Tabberner in the *Morning Chronicle* for Sept. 19th and 25th, 1849,—Leading articles in the *Morning Chronicle* for Sept. 24th, 1849, and the *Lancet* of the same month,—and Mr. Rennie's "Report to the Directors of the New River Company," 1850. For the analysis of some of the waters see Appendix C.

abundant and constant flow when these wells were first brought into common use in the early part of this century, has led, from time to time, to the hope that they might be rendered available as a source of a larger and public supply. But the rapid increase in their number of late years has, however, been attended with so constant a reduction of the quantity of water they respectively furnish, that it is now generally considered that any additional supply for public purposes cannot be expected from this source, as it seems already overtaxed by private works. Nevertheless, the total amount yet procured from these wells must be considerable, and of much value as an auxiliary mode of supply.

3. The objects proposed in the following pages are, therefore,*—

First.—To inquire into those geological conditions of structure in the water-bearing formations which determine their capacity and water-value.

Second.—To examine the *Lower Tertiary strata* and the *Chalk,* from which the present Artesian wells of London and its neighbourhood draw their supplies, and to weigh the probability of their being able to yield larger quantities of water than they now furnish.

Third.—To extend the inquiry to the strata beneath the chalk, with a view to ascertain whether the *Lower Cretaceous series* may be available as *new sources of water-supply.*

Fourth.—To show—by a comparison of the volumes and capacities of these *Tertiary* and *Secondary* formations, that the sources, which there is every probability of finding in the *Upper and Lower Greensands* beneath London, would furnish a quantity of water sufficient, possibly, for the supply of the

* A general statement of these views was communicated to the "Royal Institute of British Architects" in July last; a report of which appeared in their "Proceedings" of that month.

metropolis; or, at all events, so large as to constitute an important auxiliary supply.

Fifth.—To prove that these sources of supply are accessible at comparatively moderate depths,—that it is probable the waters would be pure and good,—and that they would rise naturally to a height much above that of the general level of the ground in London.

It may be observed also, that although the questions immediately to be discussed are of a local nature, they involve others applicable to all arenaceous strata, and which may serve to illustrate the theory of springs and water-supply in other Tertiary and Secondary districts.

4. As no Artesian wells in London have as yet been carried through the chalk, it remains to be determined what would be the result of such an operation; and this part of the inquiry being one of considerable importance will also be discussed at some length. Judging from analogy, there is every reason to suppose that such a work would be as successful here as they have already been in Paris, Elbœuf, and Tours; or rather it will be shown that the conditions in this country are in every respect more favourable.

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5. There are two sources of water-supply to the land,—one from the rain and snow falling upon the surface generally, —the other from streams produced by the melting of snow in mountain districts. The latter is not within the range of this inquiry.

The removal of the rain water from the immediate surface on which it falls is effected, first, by streams and rivers; secondly, by evaporation and vegetation; and thirdly, by absorption into the strata,—the proportionate operation of these three causes depending upon the geological struc-

ture of the country, and upon the climate. The subject is at present involved in much obscurity,—exact experiments are wanting; but still, where the geological features are well marked, some rough estimate of the relative power of these different agencies may be formed.

When the surface of the country consists of impermeable clays, or of close-grained rocks, the bulk of the water is removed either by drainage in streams and rivers; or else, if the fall of the land be unfavourable, by evaporation. But where the strata at the surface are porous and permeable, a large portion of the rain will pass into the interior of the strata, to be rendered back again, naturally by springs, or artificially by wells.

6. There are two primary geological conditions upon which the quantity of water that may thus be supplied to the water-bearing strata depend: 1st. The extent of superficial area presented by these deposits, whereby the quantity of rain-water received on their surface in any given time, is determined:—2nd. The lithological character and thickness of the strata, whereby the proportion of water that can be absorbed, and the quantity which the whole volume of the permeable strata can transmit, is regulated. The operation of these general conditions will constantly vary in accordance with local phenomena, all of which must, in each separate case, be taken into consideration.

These are all points essentially related to Geology, constituting but an application of its principles to this particular case. The numerical data required can as yet scarcely be said to exist; for even in our best geological maps, the superficial areas occupied by the different Tertiary and Upper Secondary formations around London, are not laid down with sufficient accuracy for an inquiry of this kind, nor was it needed for general geological purposes. Closer determinations of the thickness of the strata are also necessary.

7. If the thick mass of clay on which London stands, and which extends for many miles in most directions, always formed, as it frequently does, the surface of the ground, then almost all the rain-water falling upon it would be carried off into the usual surface channels, or would remain on the surface, until removed by evaporation into the atmosphere.* But this clay is very frequently covered by an irregular bed of flint gravel,† not sufficiently thick to hold any very large quantity of water, and yet porous enough to allow of the ready removal, by infiltration, of much of the rain-water from the surface.

On reaching the bottom of this bed of gravel, the water is preserved from evaporation by the superincumbent mass of gravel, and is prevented from descending lower by the underlying surface of impermeable London clay. It therefore spreads out in a sheet and is retained in the lower part of the gravel above that deposit, affording an easily accessible although limited source of supply (by means of shallow wells‡) over large tracts of country.

8. If, instead of a few feet of gravel resting on impervious clay, there should exist a regularly stratified deposit of permeable strata, overlying others which are impermeable but not covered by any such beds,—then, other conditions being favourable, the water will accumulate in the lower part of this deposit in proportion to its volume.§ But in strata occupying such a position, as well as in the gravel, all wells must be sunk by digging, and not bored, to the natural water-level, there being no superincumbent impermeable

* Such a district would, in the latter case, present the extremes, in cold wet-weather, of damp and moisture, and in hot weather, of dryness and want of water.

† This gravel is not represented on the map.

‡ This source still supplies many of the old public pumps of London (p. 36).

§ See some observations on this subject by Dr. Buckland in his Bridgewater Treatise, p. 70.

stratum to keep down the water at a level below that to which it would naturally have a tendency to rise.

When the strata are thick and porous, as the sands around Bagshot, Reigate, or Woburn, a large portion of the rain-water is at once absorbed, and permeates freely through them. The infiltration is in proportion to the absence of any admixture of clay in the mass of the sands. But if, instead of this incohesive structure, the strata should be more solid and compact, then, although they will imbibe and retain a certain quantity of moisture by capillary attraction, water will not pass freely through them, except by means of cracks and fissures in the rock. Consequently such deposits (oolites, limestones, some sandstones, &c.), instead of holding definite quantities of water in proportion to their masses, will hold indefinite quantities proportioned only to the number and magnitude of the crevices and fissures by which they are traversed; and the water so held will not pass indifferently in any direction, but must follow the irregular and uncertain channels presented by these joints and fissures.

Where the water is thus diverted into comparatively few channels, the springs issuing from such rocks will frequently, where the mass of the deposit is large, be more abundant than in more permeable strata, in which the distribution of the water is more equable, and the issues more numerous. It is on this account that the springs in the chalk valleys, and at the foot of the chalk downs, are so large and powerful in comparison with those generally in the Greensand and other sandy districts.

9. But when the permeable strata not only repose upon, but are also covered by others which are impermeable, the water, which passes into the strata where they come to the surface, and follows their course underground, will be forcibly restricted within fixed limits by the superincumbent impermeable beds; and if these latter should be anywhere

pierced or bored through, then, on reaching the underlying permeable strata, the water therein will tend to rise through the opening to a height proportionate to the level at which it stands in those strata at their outcrop,—and if that should be higher than the surface of the ground where the bore has been made, the water will not only rise to the surface, but may overflow.

It is to this last-mentioned form of well that the term *Artesian* has been applied. The name owes its origin to the supposed fact of these wells having been originally constructed*

* The construction of these wells revived, rather than originated, in Artois. They have also been long in use in Italy, and a few other parts of Europe. Shaw, in his "Travels in Barbary," mentions wells in the desert of Sahara which were evidently Artesian. That they were known also to the ancients admits of no doubt. Arago refers to a quotation of Niebuhr, from Olympiodorus, who states that in his time (the 6th century) wells were constructed, in the oases of the desert, 200, 300, and sometimes 500 "*aunes*" deep, and that from these wells streams of water were thrown out, which were used for the irrigation of the country.

The most ancient Artesian wells of which I can find any record, are those mentioned in a communication to the French "Institut," by M. Lefebvre. They were discovered by M. Ayme in the Oasis of Thebes, and have there been, in places, so numerous, that the ground is, as it were, riddled (*criblé*) by them.† They are now all neglected and in ruins; but from an examination of them by M. Ayme, it appears that a square shaft six to ten French feet on the sides was first sunk through about 80 feet of clays and marls, reaching at this depth a mass of limestone, through which the work was continued by a bore of six to eight inches in diameter at top for about 300 feet, when strata of water-bearing sands were met with. A triple layer of wood was used for lining the sides of the shafts, the decay of which has caused their stoppage by the falling in of the ground. The bore in the limestone probably did not require tubing.

So abundant seems to have been the supply, that the water from these sands not only rose through the bore in the limestone, and filled the shaft above, but appears, from the precautions taken, to have overflowed on arriving at the surface. The distant mountainous region of the kingdom of Darfur, 10° further south, is supposed to be the district in which the water-bearing strata come to the surface, and which thus furnished to the ancient Egyptians, in this nearly rainless country, an abundant and constant supply of water. The great thickness of the limestone rock, and the style of their construction, render these works very remarkable.

Ayme Bey further states that in several oases of the Libyan desert, where there are no rivers or springs, and it never rains, the population, although now very scanty,

† Comptes rendus de l'Acad. des Sciences, Vol. VII. p. 595, 1838. Vol. XIV. p. 917, 1842.

in the county of Artois (now included in the *département du Pas de Calais*) in the north of France, where the geological structure of the country is singularly favourable for their easy and economical construction.* (See Appendix A.)

These wells have been in use in this part of France from a very early period. There is one, the depth of which is not known, now in action at Lillers, that is said to have been made in 1126, and never to have shown any variation in its yield of water.†

was formerly large, having been then supplied by Artesian wells, which have been allowed to fall into decay. So sound appears to have been the principle of their construction, and so well preserved are the more essential parts of these works, that Ayme Bey has cleared out and restored several of them with perfect success.

These, however, are not solitary instances. Artesian wells appear to have been common generally in the East at a very early period. The wells known as the "Wells of Solomon," in the flat and parched plain of Tyre, are, it is suggested by Lamartine ("Travels in the East") probably of this description. He states that they form three reservoirs of clear and running water, each from sixty to eighty feet in circumference, and of depth unknown. They are elevated about twenty feet above the level of the plain, and the water is perpetually running over their sides in quantity sufficient to give motion to the wheels of mills, and is still conveyed by aqueducts to Tyre. So old are these wells that the tradition is, that Solomon caused them to be constructed in return for the services rendered him by Tyre in the building of the Temple. I must, however, observe that other travellers have considered them merely as springs with walls built round them to dam in the water.

* For details respecting the construction of Artesian wells I would refer to M. Garnier's "Traité sur les Puits Artésiens," Paris, 1826 ; or for the more theoretical investigation relating to them, and for many historical details of interest, to M. le Vicomte Hericart de Thury's "Considérations Géologiques et Physiques sur la Théorie des Puits forés, ou Fontaines Artésiennes," Paris, 1826 ; and his "Rapport sur la concours pour le percement des Puits Forés," etc., Paris, 1831. The best geological account of the strata traversed by these wells in France, and of the geological position of the waters, is contained in a Paper by M. D'Archiac, "Sur la Formation Crétacée," etc., in the "Mémoires de la Société Géologique de France," 2nd Ser. Vol. II., and in the very complete special work on this subject by M. Degousée. "Guide du Sondeur, ou Traité Théorique et Pratique des Sondages," Paris, 1847. M. Arago also gave a very able notice of these wells in the "Annuaire du Bureau des Longitudes," for 1835. In this country we are almost entirely without works on the practical part of the subject, with the exception of the useful "Rudimentary Treatise on Well-digging, Boring, &c.," by Mr. J. G. Swindell: Weale, 1849. Matthew's "Hydraulia" does not treat of this question.

† This, of course, must be very conjectural.

Of late years these wells have been extended over almost the whole of the Chalk and Tertiary districts of the north and centre of France, and have been generally found to succeed.

As the supply of water by Artesian wells in France affords several points of comparison, and is interesting on account of its bearing on the same question in this country, I have subjoined a short account of some of them, especially of those of Grenelle and Calais, in Appendix A.

II.—GENERAL PHYSICAL CONDITIONS.

§ 2. *On the Geology of the Country around London, with reference to the position of the Water-bearing Strata.*

10. Before entering upon the general question, it may be useful to give a very short description, or rather outline, of the Geology of the district under review.

London stands on Tertiary strata,—beneath which experience has proved the existence of the Chalk; and induction leads us to presume that beneath that upper member of the Cretaceous series we should find the several lower members of the same series.

With regard to the superficial areas which the different members of these two groups respectively occupy, it will be found that, commencing at a point near Hungerford, in Berkshire, and proceeding eastward, the Tertiary series gradually expand, and form a long irregular triangular area, of which the base extends from Deal in Kent to Orford in Suffolk. The Eocene or older Tertiary strata, which occupy this tract of country, consist of the three following groups.*

First. An upper group, composed chiefly of permeable, loose siliceous sands, from 300 to 400 feet thick, known as the *Bagshot Sands.*

Second. A middle group of impermeable, dark brown and bluish grey tenacious clays, attaining in some places a thickness of 400 to 500 feet. This deposit is termed the *London Clay.*

* The *Crag*, being confined to Norfolk, Suffolk, and part of Essex, is omitted.

Third. A lower group, composed of impermeable mottled clays and of permeable sands, very variable in their composition and structure, and of a thickness varying from 25 to 130 feet. This group I have temporarily designated merely as the *Lower Tertiary Strata.**

11. As the *Bagshot Sands* do not form a deposit adapted to the construction of Artesian wells, they scarcely come within the scope of this inquiry, and will be very briefly noticed.† Their nearest point to London is at Highgate and Hampstead, which hills, however, they but thinly cap. The main mass of these sands extends from Esher on the east to near Strathfieldsaye on the west, and from near Guildford on the south to Ascot and Virginia Water on the north, forming an elevated tract, composed, in the greater part, of sandy heaths. They are placed on too high a level to allow of very large permanent accumulations of water within their mass. The rain which falls on them is in places partly kept out by a thin coating of drift and by thick beds of gravel, but more usually it percolates readily through the sands, which form the hills and higher grounds, and is thrown out again,—either by the central beds of clay, subordinate to the *Bagshot Sands*, or by the underlying London clay,—on the flanks of the hills, or at their base in the valleys.‡

12. The *London clay* forms a trough-shaped mass of very variable breadth and thickness, perfectly impervious to water, which drains over its surface. At London, where it is from 100 to 200 feet thick, it is, however, usually covered by a bed of pervious gravel.

* The beds here referred to are those usually known as the *Plastic Clay Formation*, a term which I think objectionable, and therefore have not used.

† When the present volume was commenced I was not aware of the important inquiry upon which the "General Board of Health" was engaged, with reference to this formation.

‡ For some account of the Bagshot Sands see a Paper by Mr. Warburton, in the Trans. of Geo. Soc., 2nd Ser. Vol. I; and another by the author in the Quart. Journ. Geo. Soc. Vol. III.

The *Lower Tertiary sands and clays* beneath the London clay form one of the sources of supply of water to the Artesian wells of London and its neighbourhood. They are here from seventy to eighty feet thick, but, owing to their irregularities of structure and position, their *water-value* is comparatively small, considering the area over which they are spread.

13. The *Chalk* occupies a broad tract of country in Kent and Surrey, passes beneath the Tertiary strata in the valley of the Thames at a depth of from 150 to 400 feet, and reappears in the hills of Hertfordshire, Buckinghamshire, and adjacent counties. In consequence of the insufficiency of water supply in the Lower Tertiary strata, the Artesian wells at London are often carried down into this formation, to which a thickness of from 700 to 1000 feet has been assigned. Water percolates through it readily by means of fissures, but it is a question as to the quantity which may be thus held and transmitted.

14. The Lower Cretaceous series, which are next in descending order to the chalk, consist of—first, the *Upper Greensand*, a permeable deposit 20 to 150 feet thick;—second, the *Gault*, an impermeable mass of dark grey clay, 100 to 150 feet thick;—and third, beneath this is the *Lower Greensand*, which varies in its thickness from 15 or 20 to 400 and 700 feet, and is generally very permeable. This latter reposes in Kent and Surrey upon the impermeable beds of the *Weald clay*, and in Bedfordshire and adjoining counties, on the equally impermeable *Kimmeridge clay*. (See Map.)

The Tertiary strata occupy the centre of the district under consideration, while all the other deposits crop out successively from below them in the country to the north and south of London, and converge at their greatest depth to a point below the valley of the Thames. A reference to the Map will exhibit better than can be done by description, the extent of country occupied by each of the above-mentioned deposits,

and will, with the sections, serve to indicate the probable position of the different groups as they pass beneath the surface under London.

15. In comparing between the relative productive water-capacity of any two group of strata, a general knowledge of the geology of the district is not enough. Exact physical details of structure, volume, and superficial area, are necessary. Although the boundary lines of many of the Secondary formations in the west and north of England are laid down upon our geological maps with great accuracy, this is far from being the case with regard to the boundaries of the Tertiary formations around London. The water-bearing Lower Tertiary strata are usually represented as occupying a superficial area much too large. Nor are we yet in possession of sufficient information on many points, connected with their composition and structure, needed for an inquiry of this description.

It is to supply in some measure this deficiency, and as a base for further observations, that the details of the Tertiary strata are given in the following pages at a length which may appear tedious, and almost unnecessary, were it not for the importance of the question ultimately to be resolved.

Of the geological relations of the strata below the chalk, we have much more complete accounts. The valuable Memoirs of Dr. Fitton,* "On the Strata beneath the Chalk," with those of Dr. Mantell,† Sir Roderick Murchison,‡ Mr. Lonsdale,§ Mr. Austen,|| and others, on different portions of

* Annals of Philosophy 1824, pp. 365 and 458.—Trans. Geo. Soc. 2nd Series, Vol. IV. Part ii.—and Quart. Journ. Geo. Soc. Vol. I. II. and III.

† "Geology of the south-east of England,' 1833. "Sketch of the Geology of Surrey," 1840, and "On the Geological Structure of the Country seen from Leith Hill," 1845. These two last will be found in "Brayley's History of Surrey."

‡ Trans. Geo. Soc. 2nd Series, Vol. II.

§ Trans. Geo. Soc. 2nd Series, Vol. III.

|| Proc. Geo. Soc. Vol. IV. pp. 167 and 196.

the Greensand districts, have established the general geological characters and relations of the different members of the Cretaceous series around London.* These descriptions, combined with the range of the strata as given by Dr. Fitton in his Map of the Greensand district in the work just quoted, and since laid down with his assistance in the last edition of Mr. Greenough's Geological Map of England, have, with a few alterations,† afforded me the data whereby to estimate the dimensions and water-capacities of these strata.

I cannot conclude these observations without expressing my great obligations to Dr. Fitton for his valued criticism and the kindest assistance constantly afforded me in the progress of this work.

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16. The stratified formations‡ of which England is composed, dip one under the other in general at small angles of inclination (fig. 1), and range underground to very variable depths.

* Of the Chalk itself, with the exception of a Paper on the Dover district, by Mr. Phillips in the Trans. Geo. Soc. Vol. V., we have few particulars.

† These alterations have reference chiefly to points of physical detail. I have in several instances, especially in Oxfordshire, given greater extension to the area of the Lower Chalk, as well as occasionally to the Upper Greensand, and have diminished somewhat that of the Gault. The Lower Greensand I have in some places expanded, but on the whole have reduced it considerably.

‡ To make the subject clearer to the non-geological reader, the following definitions may be useful:—

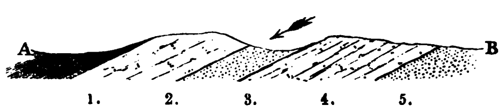
"*Formation*" in Geology means a series of strata,—which may be only a few feet thick, but usually varying from a few hundred to several thousand feet,—characterized by containing throughout the remains of similar animals and plants, and supposed to have been formed during a period of the earth's history, throughout which the same races lived and flourished undisturbed at any given point by any very marked and important changes of land or sea.

The mineral character of a *Formation*, within short distances, usually exhibits considerable similarity throughout its mass, or else presents constantly recurring characters,—as, for instance, the Chalk formation (North and South Downs); the Oolite formation (hills around Bath); the Mountain Limestone formation (hills of Derbyshire). The *strata* of the different *formations* consist of a number of layers of rock, clay, or sand, to each single layer of any of which the terms *stratum* or *bed* are applied indiscrimi-

The water draining off the surface of the country A B will flow from the hills formed by the formations 2 and 4 re-

Fig. 1.

SOUTH. NORTH.

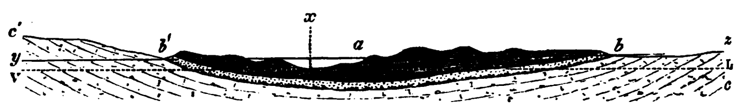


spectively into the valleys occupied by the outcrop of the strata 1, 3, and 5; and, if these formations consist of permeable beds of sand or sandstone, then a portion of the drainage waters will sink through, and accumulate in them, until they find some outlet either natural or artificial.

17. When the strata dip and rise again within a moderate

Fig. 2.

SOUTH. NORTH.



distance, as shown in fig. 2, where they dip to the south at *b* and *c*, and rise to the south *b′* and *c′*, it constitutes the

nately; sometimes the word *Deposit* is used in speaking of a stratum or bed, at times it is applied to designate a group of strata forming a subdivision of a formation, and is now frequently substituted for the term "formation" itself. In the same way *Series* is sometimes applied to a number of consecutive beds or strata, and at other times to a number of consecutive formations of one great geological division. In the latter case the term *System* is, however, more usually applied. The context will generally indicate the meaning intended.

The *Outcrop* of a bed or of a formation is that part of it which comes to, and forms, the surface of the country. Thus the formations 1, 2, 3, 4, and 5, *crop out* on the line of country between A and B (fig. 1). The outcrops of 1 and 3 occur in the valleys, and those of 2 and 4 form the intervening ranges of hills.

The *Dip* is the angle formed by the plane of stratification with a horizontal plane on the surface. Thus the dip of the strata in fig. 1, is in the direction shown by the arrow, at an angle of 27° south.

The *Strike* of a deposit is a line on the surface, drawn at right angles to its dip. The strike of the strata in fig. 1 is therefore east and west.

The *Range* of a stratum, or of a formation, denotes the course of its outcrop on the surface;—"underground range" is sometimes used in describing the prolongation of the whole mass beneath the surface of the ground.

form of geological structure best adapted for the construction of Artesian wells. But for this object it is necessary that *b* should consist of permeable sands, that can absorb and transmit the rain water falling on its surface, and *a* and *c* of impermeable strata, through which water cannot pass. The water thus supplied, together with a portion derived from the drainage of the adjacent hills, will then accumulate in *b*, as in a natural reservoir, and if the quantity drawn off from it be less than the quantity supplied, the reservoir so circumstanced will keep constantly full.* In a well sunk in any part of the country between the outcropping edges of the strata at *b* and *b′*, the water will rise at the surface with a force proportionate to the depth of the top of the shaft below a straight line drawn from *b* to *b′*, or the distance between the lines *y*, *z* and V, L. Let, for example, such an opening be made through the superincumbent beds of clay *a* at *x*. It follows that the water would there rise to the level of the line *y*, *z*, provided that all the ducts were free, and time were given for its equilibrium to be established.

Practically, however, this height will depend in a great measure upon the distance of the point *x* from the outcrop of the strata *b*, upon the mineral character presented by *b*

* This I believe to be the theory now universally adopted. A curious but very general notion prevailed formerly, which accounted for the phenomena of springs and underground sources, by supposing that the sea penetrated through the strata at its bottom, and was by that means conveyed to any distance under the land, forming a water level almost constant with that of the sea. The extent of filtration caused, it was assumed, its salts to separate from it, and thus rendered the water pure and fresh. That portion of the water which descended to greater depths, where the central heat acted more strongly upon it, being converted into vapour, and rising through the fissures of the rocks, became condensed again on approaching the surface, especially in mountainous districts, and issued in the form of springs. This opinion originated in erroneous views with regard to the permeability of strata at the surface of the earth, it being supposed that rain water never penetrated beyond the depth of a few feet, and that some springs rising on high hills had no higher ground to draw their supplies from. Experiment and observation have proved both these positions to be wrong.

throughout that distance, and upon variations of level of the outcrop.

The general conditions of geological structure of the Artesian wells in London and its neighbourhood,* are such as has just been described, *a* being supposed to represent the London clay, *b* the beds of sand and mottled clays beneath it, and *c* the chalk;—this latter allowing, however, of the passage of water to a considerable extent, and constituting in itself a partially water-bearing deposit (see ¶ 57).

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§ 3. *Geological Conditions affecting the Value of the Water-bearing Deposits, illustrated in their application to the Lower Tertiary Strata.*

18. Having premised thus much as to general geological structure, I proceed to the consideration of the less understood conditions which affect the supply of water in the water-bearing strata. From a better acquaintance with the Tertiary strata, and not on account of their relative importance, I purpose confining myself for illustrations in this discussion to the Tertiary deposits exclusively, as the same mode of inquiry will apply with but little modification to any other formation: whilst by using them as examples, one of the objects of this inquiry will be forwarded. The main points are—

First.—The extent of the superficial area occupied by the water-bearing deposit.

Second.—The lithological character and thickness of the water-bearing deposit, and the extent of its underground range.

Third.—The position of the outcrop of the deposit, whether

* The number of Artesian wells (including both the sand and chalk wells) in and immediately around London is variously estimated at from 300 to 500, if not more.

in valleys or on hills; and whether its outcrop is denuded* or covered with any description of drift.†

Fourth.—The general elevation of the country occupied by this outcrop above the levels of the district in which it is proposed to sink Artesian wells.

Fifth.—The quantity of rain which falls in the district under consideration, and whether, in addition, it receives any portion of the drainage from adjacent tracts, where the strata are impermeable.

Sixth.—The disturbances which may affect the water-bearing strata and break their continuity, whereby the subterranean flow of water would be impeded or prevented.‡

To proceed now to the application of these questions, in the particular instance of the Lower Tertiary Strata.

The reader who does not wish to follow through the amount of detail, which, although necessary as data in evidence, is not essential to the comprehension of the argument, can pass on to p. 93, where the general question is resumed, and afterwards a summary given of comparative results, in which the main facts respecting the water-bearing strata of the *Lower Tertiaries*, and *Upper*, and *Lower Greensands*, are recapitulated. Reference can be made back to the intermediate pages in case of information being required on any particular point.

The question of the Chalk formation, with regard to its value as a water-bearing deposit, forms, however, an exception to this arrangement. It is discussed by itself as a separate and independent inquiry (see § 5).

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* The action which has operated the excavation of the valleys, and of which the result is termed "denudation," has, in the country around London, in some places left the surface entirely bare; as, for example, in the case of the London clay at Primrose Hill, or of the chalk on the south Downs around Brighton, or, still more strikingly, the hills around Tunbridge Wells. In these instances, the clay, chalk, and sandstones come close to the surface, and are merely coated with a few inches of loose earth.

† Drift is a term applied to superficial accumulations of gravel, clay, sand, or brick-earth, which are usually, but not always unstratified, and dispersed with much irregularity over the face of almost every country. Thus the London clay at Clapham Common, Kensington, and Hyde Park, is covered by a drift of gravel; at West Drayton by one of gravel and brick-earth; and the chalk on the hills around Ware is covered by other forms of drift in the shape of clays, gravel, and sand.

‡ Mr. E. W. Brayley has directed my attention to a passage in the Life of William Smith, by Prof. J. Phillips, giving an account (p. 80—86) of some obervations of Mr. Smith on the causes regulating a supply of water to a well

19. *With regard to the first question*, it is evident that a series of permeable strata encased between two impermeable formations can receive a supply of water at those points only where they crop out and are exposed on the surface of the land. The primary conditions affecting the result depend upon the fall of rain in the district where the outcrop takes place; the quantity of rain-water which any permeable strata can gather, being in proportion to the magnitude of their superficial areas. If the mean annual fall in any district amounts to twenty-four inches, then each square mile will receive a daily average of 950,947 gallons of rain water. It is, therefore, a matter of essential importance to ascertain, with as much accuracy as possible, the extent of exposed surface of any water-bearing deposit so as to determine the maximum quantity of rain-water it is capable of receiving.

In deposits of so loose and friable a character as those of which the country around London consists, it is difficult accurately to trace the outcrop of any stratum. The gentle slopes of the hills, the absence of hard rocks, the high cultivation, and luxuriant vegetation, combining to conceal the geological features of the district.*

One side of the district occupied by the Lower Tertiary strata is bounded by the chalk, and this line of boundary, from the distinct mineral character of the rock, there is no difficulty in determining. On the other side is the London clay, and there the line of division is generally very obscure,

in Wiltshire. They are of much interest, as showing at that early period (1816) in Geology the application to this subject of many of the considerations mentioned above.

* This difficulty of determining the geological structure of the country by sections at the surface, had led me for some years past to collect all sections of wells, and had thus supplied me with much of the data connected with the Tertiary strata required for this inquiry. The late Dr. James Mitchell, a most zealous geologist, and who for many years diligently studied the country around London, had paid, however, far more attention to this particular subject of wells, and I am indebted to him for much valuable information upon it. His notes also have been obligingly placed in my hands by his nephew, Mr. J. Templeton, of Exeter.

and has led to far too great* an extension of the tract occupied by the Lower Tertiary strata. (See Map.)

20. The surface formed by the outcropping of any deposit in a country of hill and valley is necessarily extremely irregular, and it would be difficult to measure, in the ordinary way, the area of such a district; I have therefore used another method, which seems to give results sufficiently correct for our present purpose.† I find by it that the area occupied by the outcrop of the beds between the London clay and the chalk, is equal to about 354 square miles. This includes the whole district from Hungerford in Berkshire to the Reculvers on the coast of Kent on the one side, and from Hungerford to Woodbridge in Suffolk on the other, embracing all the outcrop connected in unbroken line with the central mass of London clay, but excluding all outliers or partly detached portions (excepting those in Kent) the underground drainage from which is intercepted by want of continuity in the strata.

21. *The second question relates to the effect which the mineral character of the formation will have upon the quantity of water which it may hold and transmit.* If the strata consist of sand, water will pass through them with facility, and they will also hold a considerable proportion between the interstices of their component grains‡; whereas a bed of pure clay will not allow of the passage of water. These are the two extremes of the case; the intermixture of these materials in the same bed will of course, according to their relative propor-

* More than double.

† A plan borrowed from the geographers—that of cutting out from a map on paper of uniform thickness and on a large scale (one inch to the mile), and weighing the superficial area of each deposit. Knowing the weight of a square of 100 miles, cut out of the same paper, it is easy to estimate roughly the area in square miles of any other surface, whatever may be its figure. The experiments were repeated several times, and mean results are given. The weights were taken to a tenth of a grain.

‡ See Table, p. 114.

tions, modify the transmission of water. I find by experiment that a siliceous sand of ordinary character will hold on an average rather more than one-third of its bulk of water, or from two to two and a half gallons in one cubic foot. In strata so composed, the water may be termed "free," as it passes easily in all directions, and, under the pressure of a column of water, is comparatively but little impeded by capillary attraction. These are the conditions of a true permeable stratum. Where the strata are more compact and solid, as in sandstone, limestone, and oolite, although all such rocks imbibe more or less water, yet the water so absorbed does not pass freely through the mass, but is held in the pores of the rock by capillary attraction, and parted with but very slowly; so that in such deposits water can be freely transmitted only in the planes of bedding and in fissures.

If the water-bearing deposit be of uniform lithological character over a large area, then the proposition is reduced to its simplest form; but when, as in the deposit between the London clay and the chalk, the strata consist of variable mineral ingredients, it becomes essential to estimate the extent of these variations; for very different conclusions might be drawn from an inspection of the Lower Tertiary strata at different localities.

22. In the fine section exposed in the cliffs between Herne Bay and the Reculvers, a considerable mass of fossiliferous sands is seen to rise from beneath the London clay.

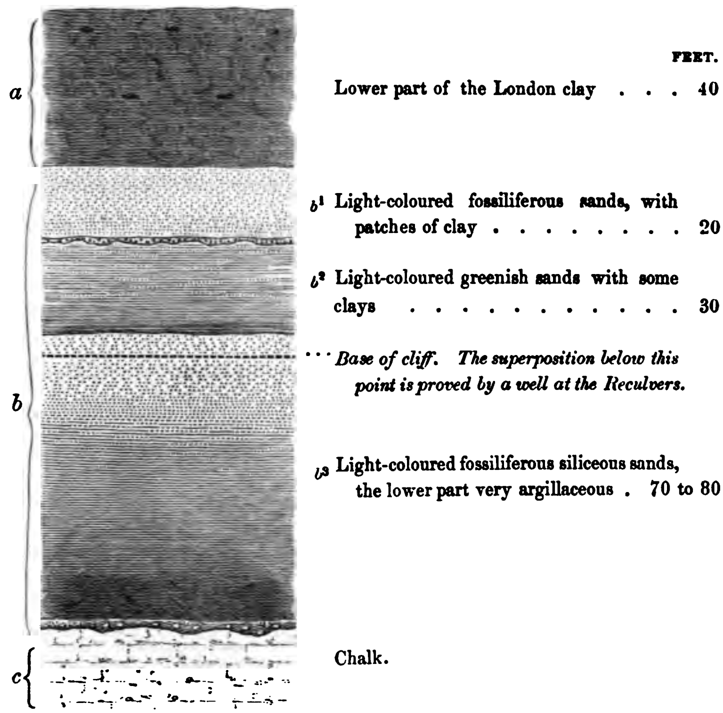
The annexed diagram represents a view of a portion of this cliff a mile and a half east of Herne Bay, and continued downwards, by estimation below the surface of the ground, to the chalk.

In this section there is evidently a very large proportion of sand, and consequently a large capacity for water.

Again at Upnor, near Rochester, the sands marked b^3, in Fig. 3, are as much as sixty to eighty feet thick, and

continue so to Gravesend, Purfleet, and Erith.* In the first of these places they may be seen capping Windmill Hill; in the second, forming the hill (now nearly removed) on which the experimental light-house is built; and in the third in the large ballast pits on the banks of the river. The average

Fig. 3.†



thickness of these sands in this district may be about fifty to sixty feet. In their range from east to west, the beds b^2 become more clayey and less permeable, and b^1 very thin. As we approach London, the thickness of b^3 also diminishes.

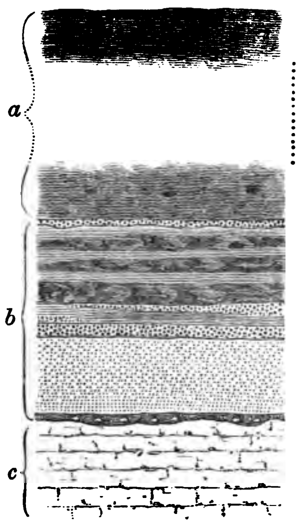
* For descriptions of several sections in this district see a paper by Mr. J. Morris, in Proc. Geol. Soc. Vol. II. p. 450.

† This section, as well as those in Figs. 4 to 7, is upon a vertical scale of fifty feet to the inch.

In the ballast pits at the west end of Woolwich,* this sand bed is not more than thirty-five feet thick, and as it passes under London it becomes still thinner.

23. The annexed diagram (Fig. 4) represents a general or average section of the strata on which London stands.†

Fig. 4.



		FEET.
	London clay	100 to 150
b^1	Sands, pebbles, and shells‡ . .	1 to 3
b^2	Sands, mottled clays, and pebble-beds very irregularly interstratified	15 to 45
b^3	Light-coloured siliceous sands .	20 to 50
	Chalk.	

The great increase in the proportion of the argillaceous strata, and the decrease of the beds of sand, in the Lower Tertiary

* For detailed sections of the Woolwich and Lewisham pits see a Paper by Dr. Buckland, in the Transactions of the Geological Society, Vol. IV. p. 276; also, Philipps and Connybeare's Outlines of the Geology of England, p. 47.

† For some valuable details on this subject, see the work recently published by Mr. R. Mylne, "On the strata beneath London," in which the well-sections, and the levels of the strata, are given with great accuracy.

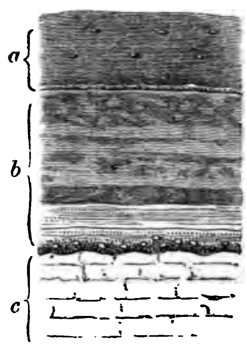
‡ There is generally a small quantity of water found in this bed in parts of the neighbourhood of London. Owing, however, to the constant presence of green and ferruginous sands, traces of vegetable matter and remains of fossil shells, the water is usually indifferent and chalybeate. The well-diggers term this a slow spring. They well express the difference by saying that the water *creeps up* from this stratum, whereas that it *bursts up* from the lower sands b^3, which is the great water-bearing stratum. In the irregular sand beds, interstratified with the mottled clays between these two strata, water is also found, but not in any large quantity.

strata, is here very apparent, and from this point westward to Hungerford, clays decidedly predominate; while at the same time the series presents such rapid variations, even on the same level, and at short distances, that no two sections are alike.

24. On the southern boundary of the Tertiary district from Croydon to Leatherhead, the sands, b^3,* maintain a thickness of twenty to forty feet, whilst the associated beds of clay are of inferior importance.

Crossing over to the northern boundary of the Tertiary district, we will take another section (Fig. 5), representing the usual features of the deposit in that part of the country. It is from a cutting at the brickfield, west of the small village of Hedgerley, six miles northward of Windsor.

Fig. 5.



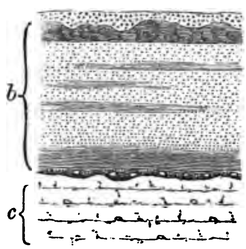
	FEET.
London clay.	
Mottled clays, with a few subordinate layers of sand	30
Fire-brick earth	5
Mixed green-sand, clay, and flints	5
Chalk.	

25. Here we see a large development of the mottled clays, and but little sand. A somewhat similar section is exhibited at Oak End, near Chalfont St. Giles. But to show how rapidly this series changes its character, the section of

* I am not sure that these sands can geologically be identified with those b^3 on the same level further eastward. As, however, they occupy the same relative position as b^3 does at Woolwich, they may for our present purpose be considered as their equivalent.

a pit, only a third of a mile westward of the one at Hedgerley, is annexed, in Fig. 6.

Fig. 6.



	FEET.
Ochreous gravel	2 to 3
Mottled clay	4
Light-coloured sands, with a few irregular seams of mottled clay	30
Light bluish clay	4
Greensand, clay, and flints	2
Chalk.	

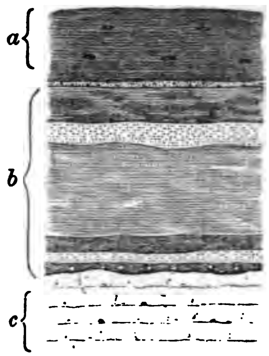
In this latter section the mottled clays have nearly disappeared, and are replaced by beds of sand with thin seams of mottled clays. At Twyford near Reading, and at Old Basing, near Basingstoke,. the mottled clays again occupy, as at Hedgerley, nearly the whole space between the London clays and the chalk. Near Reading, a good section of these beds was exhibited in the Sonning cutting of the Great Western Railway; they consisted chiefly of mottled clays. At the Katsgrove Pits, Reading, the beds are more sandy.*

26. Many other sections might be given; but as they do not present any exception to the general rule, we will pass to one at the western extremity of the Tertiary district at Pebble Hill, near Hungerford (Fig. 7). Here again the mottled clays are in considerable force, sands forming the smaller part of the series.

These sections (Nos. 3 to 7) give a fair average representation of the strata generally between the London clay and the chalk.

* For details of this Section, see Dr. Buckland's paper in the 4th vol. Trans. Geol. Soc. Several sections, illustrative to some extent of the Lower Tertiary strata, are given in a paper of the author's, published in the Quart. Journ. Geol. Society for August, 1850: there, however, the argument is connected with the organic remains of the strata.

Fig. 7.



	FEET.
London clay.	
Mottled clays	10
Whitish sands	6
Sandy clays, slightly mottled	23
Dark red tile-clay	4
Light-coloured sands	3
Clay, green sand, flints, and remains of ostreæ	2
Chalk.	

27. Westward of London, the Lower Tertiary strata differ so much from those to the eastward of it, that it will be advisable to examine the two districts separately, as they have a very unequal bearing upon the Artesian wells of the Metropolis. The following lists exhibit the aggregate thickness of all the beds of sand occurring between the London clay and the chalk at various localities in the Tertiary district. It will appear from them that the mean result of the whole is very different from any of those obtained in separate divisions of the country. The mean thickness of the deposit throughout the whole Tertiary area may be taken at sixty-two feet, of which thirty-six feet consist of sands, and twenty-six feet of clays, but as only a portion of this district contributes to the water-supply of London, it will facilitate our inquiry if we divide it into two parts, the one westward of and including London, and the other eastward of it,—introducing also some further subdivisions into each.*

* The fractional parts of feet are omitted, and the few beds of uncertain mineral character are divided.

Measurement of sections Westward of London.

On or near the Southern boundary of the Tertiary district.

	Sand ft.	Clay ft.
Streatham	30	25
Mitcham	47	34
Croydon	35?	20?
Epsom	31	23
Fetcham	35	20
Guildford	10?	40
Chinham, near Basingstoke	20?	30
Itchingswell nr. Kingsclere	22	34
Highclere	24	27
Pebble Hill, nr. Hungerford	9	39
Average	26	29

On a Central line in the Tertiary district.

	Sand ft.	Clay ft.
London:* Milbank .. 49 40; Trafalfar Sq. .. 49 30; Tottenham Court Road .. 35 30; Pentonville .. 34 44; Barclay's Brewery .. 55 42; Lombard St... 53 35; The Mint .. 49 38; Whitechapel .. 45 50	46	39
Garrett, near Wandsworth	20	52
Isleworth	17	70
Twickenham	7	50
Chobham	3	45
Average	18	51

On or near the northern boundary of the Tertiary district.

	Sand ft.	Clay ft.
Hatfield	23	2
Watford	25	10
Pinner	12	32
Oak End, Chalfont St. Giles	3	40
Hedgerly near Slough	5	45
Starveall, do.	13	20
Twyford	5	60
Sonning near Reading	12	54
Reading	16	33
Newbury	20	36
Pebble Hill	9	39
Average	13	34

The mean of these three columns gives a thickness to this formation of fifty-seven feet; of which only nineteen feet are sand, and permeable to water; and the remaining thirty-eight feet consist of impermeable clays, affording no supply of water.† The area (at the surface and underground) over which they extend, is about 1086 square miles. The other portion of the district exhibits the following results. (See Table in next page).

The average total thickness over this eastern district deduced from these nine sections gives sixty-eight feet, of

* This list might be much extended, but the above gives a fair average of these beds. For some further particulars of the London wells, see two papers, one by Mr. J. Donkin, and another by Mr. W. Gravat, in the 1st Vol. Trans. Civ. Eng.; also the sections of Mr. R. W. Mylne, with a paper by the same author "On the supply of water from Artesian wells in the London Basin, &c." (Trans. Civ. Eng., 3rd part of Vol. III.); and the series published in 1849 by the Metropolitan Commissioners of Sewers.

† In London and the neighbourhood, it would have been sufficient to have divided the group b into two parts, excluding altogether the upper one (b^1 of Fig. 4).

Measurement of sections Eastward of London.

Southern Boundary.	Sand ft.	Clay ft.	Northern Boundary.	Sand ft.	Clay ft.
Lewisham	65	26	Hertford	26	3
Woolwich	66	18	Beaumont Gn. nr. Hoddesdon	16	10
Upnor	80 ?	8	Broxbourne	28	2
Herne Bay	70 ?	50	Gestingthorpe near Sudbury	50 ?	?
			Whitton, near Ipswich	60 ?	5
Average	70	25	Average	36	5

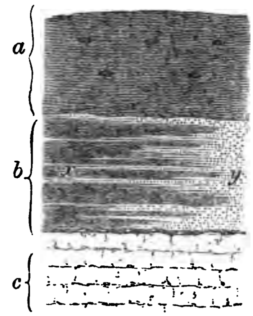
which fifty-three feet are sands, and fifteen feet clays. The larger area (1849 square miles), over which the eastern portion of the Tertiary series extends, and the greater volume of the water-bearing beds, constitute important differences in favour of this district; and if there had been no geological disturbances to interfere with the continuity of the strata, we might have looked to this quarter for a large supply of water to the Artesian wells of London.

28. From these tables it will be readily perceived that the strata of which the water-bearing deposits are composed, are very variable in their relative thickness. They consist, in fact, of alternating beds of clay and sand in proportions constantly changing.* In one place (as at Hedgerley) the aggregate beds of sand may be five feet thick, and the clays forty-five feet, whilst at another (as near Leatherhead) the sands may be thirty-five, and the clays twenty feet thick; and some such variation is observable in every locality. But although we may thus in some measure judge of the capacity of these beds for water, this method fails to show whether the communication from one part of the area to another is free or impeded by causes connected with mineral character. Now as we know that these beds not only vary in their thickness,

* The difference in the permeability of the strata arising from this cause is treated of in another part of this work. The main divisions only, into impermeable clays and variably permeable sands, are here referred to (¶ 100—109).

but that they also frequently thin out, and sometimes pass one into another, it may happen that a very large development of clay at any one place may altogether stop the transit of the water in that locality. Thus, in fig. 8, the beds of

Fig. 8.



sand at *y*, allow of the free passage of water, but at *x*, where clays occupy the whole thickness of *b*, it cannot pass. This phenomenon is, I believe, of not unfrequent occurrence in the Lower Tertiary strata *westward* of London,* but the obstruction which it may offer to the underground flow of water can be determined only by experience. It must not, however, be supposed that such a variation in the strata, *b*, is permanent or general along any given line. It is always local—some of the beds of clay commonly thinning out after a certain horizontal range—so that, although the water may be impeded or retarded in a direct course, it most probably can, in part or altogether, pass round by some point where the strata have not undergone the same alteration.

29. *To proceed to the investigation of the third point of inquiry relating to the position and general conditions of the outcrop.* This involves some considerations to which an exact value cannot at present be given, yet which require notice, as they, to a great extent, determine the proportion of water

* At the same that, I believe, the lower sands, b^3 of fig. 4, thin out.

which can pass from the surface into the mass of the water-bearing strata.

In the first place, when the outcrop of these strata occurs in a valley, as represented in figure 9, it is evident that *b* may not only retain all the water which might fall on its surface, but also would receive a certain proportion of that draining off from the strata of *a* and *c*.* This form of the surface generally prevails wherever the water-bearing strata are softer and less coherent than the strata above and

Fig. 9.

Section across the valley at Chinham, near Basingstoke.

a, London clay ; *b*, Sands and mottled clays ; *c*, Chalk ; V, L, Level of the valley.

below them. It may be observed in the Lower Tertiary series at Sutton, Carshalton, and Croydon, where a small and shallow valley, excavated in these sands and mottled clays, ranges parallel with the chalk hills. It is apparent again between Epsom and Leatherhead, and also in some places between Guildford and Farnham, as well as between Odiham and Kingsclere. The Southampton Railway crosses this small valley on an embankment at Old Basing.

This may be considered as the prevailing, but not exclusive form of structure from Croydon to near Hungerford. The advantage, however, to be gained from it in point of water-supply, is much limited by the rather high angle at which the strata are inclined, as well as by their small

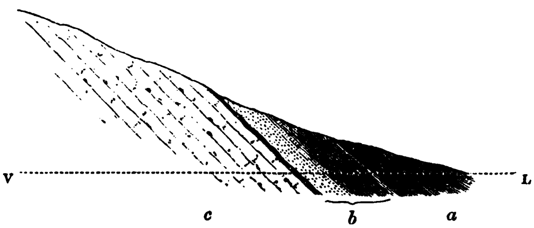
* In speaking of the drainage from off the chalk, it must be understood that it is extremely limited, especially when the surface is bare, except in very heavy rains. It is only when covered by drift, clay, or gravel, that it becomes more apparent.

development, which greatly restrict the breadth of the surface occupied by the outcrop. It rarely exceeds a quarter of a mile, and is generally very much less, often not more than one hundred to two hundred feet. The width of outcrop is nearly uniform from Epsom* to Inkpen near Hungerford (see Map).

30. The next modification of outcrop, represented in fig. 10,

Fig. 10.

Section half-a-mile east of Highclere.



is one which is not uncommon on the south side of the Tertiary district. The Strata *b* here crop out on the slope of the chalk hills, and the rain falling upon them, unless rapidly absorbed, tends to drain at once from their surface into the adjacent valleys (v, l, line of valley level).

This arrangement is not unfrequent between Kingsclere and Inkpen, and also between Guildford and Leatherhead. Eastward of London it is exhibited on a larger scale at the base of the chalk hills, in places between Chatham and Faversham, a line along which the sands of the Lower Tertiary strata, *b*, are also more fully developed than elsewhere. As, however, the surface of *b* is there usually more coincident with the valley level (v, l) of the district, it is in a better position for retaining more of the rain-fall.

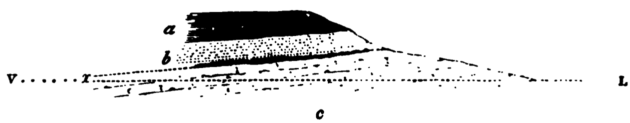
31. A third position of outcrop, much more unfavourable for the water-bearing strata, prevails generally along the greater

* Between Croydon and Epsom it is rather broader and more irregular.

part of the northern boundary of the Tertiary strata. Instead of forming a valley, or outcropping at the base of the chalk hills, almost the whole length of this outcrop lies on the

Fig. 11.

Section of the hill one mile N.E. from Hatfield.



slope of the hills (as in Fig. 11), where the chalk, *c*, forms the base of the hill and the lower ground at its foot, whilst the London clay, *a*, caps the summit, thus restricting the outcrop of *b*, to a very narrow zone and a sloping surface. This form of structure is exhibited in the hills around Reading, Sonning, Hedgerley, Rickmansworth, and Watford, (where the Birmingham Railway is carried through the strata *b* at the Bushey cutting, and at the end of it passes by an embankment on to the chalk, which occupies a lower level in the valley of the Colne); thence by Shenley Hill, Hatfield, Hertford, Sudbury, and also at Hadleigh, this position of outcrop is continued. If, as on the southern side of the Tertiary district, the outcrop were continued in a nearly unbroken line, then these unfavourable conditions would prevail uninterruptedly; but the hills are in broken groups, and intersected at short distances by transverse valleys, as that of the Kennet at Reading, of the Lodden at Twyford, of the Colne at Uxbridge, the valley from near Rickmansworth to Ruislip, and again from Watford to Pinner. Between Watford and Hatfield there is a constant succession of small valleys running back for short distances from the Lower district of the Chalk, through the hills of the Tertiary district. The valley of the Lea at Roydon and Hoddesden, is a similar and stronger case in point. The same thing occurs in the Valley

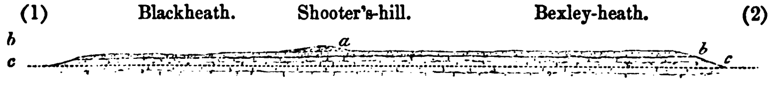
of the Stour, at Sudbury. The effect of these transverse valleys is to open out a larger surface of the strata *b*, than would otherwise be exposed;—for if the horizontal line V L, fig. 11, were carried back beyond the point *x* to meet the prolongation of *b*, then these Lower Tertiary strata would not only be intersected by the line of valley level, but would form a much smaller angle with the plane V L, and therefore spread over a larger area than where they crop out on the side of the hills.

The irregular outline produced by this structure is shown in the Map, where the constantly varying northern outcrop of the Lower Tertiary strata contrasts strongly with the thin, narrow, and comparatively regular zone formed by their southern outcrop between Croydon and Kingsclere.

32. The foregoing are the three most general forms of outcrop, but occasionally the outcrop takes place wholly or partly on the summit of a hill, as near the Reculvers, in the neighbourhood of Canterbury, of Sittingbourne, and at the Addington hills, near Croydon, in which cases the area of the Lower Tertiaries is expanded. When the dip is very slight, and the beds nearly horizontal, the Lower Tertiary sands occasionally spread over a still larger extent of surface, as between Stoke Poges, Burnham Common and Beaconsfield, and in the case of the flat-topped hill, forming Blackheath and Bexley heath (see fig. 12).

Fig. 12.

Section from Deptford (1) to Crayford (2).



a. London Clay. *b*. Lower Tertiary strata. *c*. Chalk.

Favourable as such districts might at first appear to be from the extent of their exposed surface, nevertheless they

rarely contribute to the water-supply of the wells sunk into the Lower Tertiary sands under London, the continuity of the strata being broken by intersecting valleys; thus the district last mentioned is bounded on the north by the valley of the Thames, on the west by that of the Ravensbourne, and on the east by the valley of the Cray; consequently the rain water, which has been absorbed by the very permeable strata on the intermediate higher ground, passes out on the sides of the hills, into the surface channels in the valleys.*

33. Thus far we have considered this question, as if, in each instance, the outcropping edges of the water-bearing strata, *b*, were laid bare, and presented no impediment to the absorption of the rain water falling immediately upon their surface, or passing on to it from some more impermeable deposits. But there is another consideration which influences materially the extent of the water-supply.

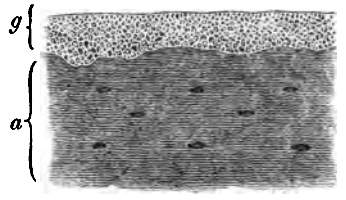
If the strata *b* were always bare, we should have to consider their outcrop as an absorbent surface of power varying according to the lithological character and dip of the strata only. But the outcropping edges of the strata do not commonly present bare and denuded surfaces. Thus a large extent of the country round London is more or less covered by beds of drift, which protect the outcropping beds of *b*, and turn off a portion of the water falling upon them.

The *Drift* differs considerably in its power of interference with the passage of the rain-water into the strata beneath. The ochreous sandy flint gravel, forming so generally the subsoil of London, admits of the passage of water. All the shallow surface-springs, from ten to twenty feet deep, are produced by water which has fallen on, and passed through

* Or into the chalk. Almost all the wells at Bexley Heath, for their supply of water, have, in fact, to be sunk into the chalk through the overlying 100 to 133 feet of sand and pebble beds (*b*).

this gravel (g) down to the top of the London clay (a) on the irregular surface of which it is held up* (fig. 13).

Fig. 13.



34. When the London clay is wanting, this gravel lies immediately upon the Lower Tertiary strata, as in the valley between Windsor and Maidenhead, and in that of the Kennet between Newbury and Thatcham, transmitting to the underlying strata part of the surface water.

Where beds of brick earth occur in the drift, as between West Drayton and Uxbridge, the passage of the surface water into the underlying strata is intercepted.

Sometimes the Drift is composed of Gravel mixed very irregularly with broken-up London clay; and, although commonly not more than three to eight feet thick, it is generally impermeable.

Another description of drift will be noticed in connexion with the chalk.

35. Over a considerable portion of Suffolk, and part of Essex, a drift, composed of coarse and usually light-coloured sand mixed with fine gravel, occurs. Water percolates through it

* These are called *land-springs*, and they constituted, formerly, a principal source of water-supply to London. Most of the old parish pumps are supplied by springs of this description. They still furnish a not unimportant supply of water, although the sewers have reduced the quantity, and, with the gas and other works, have much interfered with the quality. Mr. Tabberner calculates that they yet yield daily 3,000,000 gallons (Letter in the Daily News, 13th March, 1850. This quantity seems to me to be too large). For some account of the quality of these waters, see Appendix C.

with extreme facility, but it is generally covered by a thick mass of stiff tenacious bluish-grey clay, perfectly impervious.

Fig. 14.

Section of Balingdon Hill, near Sudbury, Essex.

1. Boulder Clay Drift.
2. Sand and gravel Drift.
a. London Clay.
b. Lower Tertiary strata.
c. Chalk.
V. L. Line of valley level.

This clay drift (Boulder-clay*) caps to a depth of from ten to fifty feet or even more, almost all the hills in the northern division of Essex, and a large portion of Suffolk and Norfolk. It so conceals the underlying strata, that it is difficult to trace the course of the outcrop of the Lower Tertiary sands between Ware and Ipswich; and often, as in fig. 14, notwithstanding the breadth, apart from this cause, of the outcrop of the Tertiary sands *b*, and of the drift of sand and gravel (2), they are both so masked by the Boulder-clay (1), that the small surface exposed can be of little comparative value.

There are also, in some valleys, river deposits of silt, mud, and gravel. These are, however, of little importance to the subject before us. Under ordinary conditions they are generally sufficiently impervious to prevent the water from passing through into the beds beneath.

36. *The fourth question for consideration, relates to the height of the districts, wherein the water-bearing strata crop*

* For a description, and an inquiry into the origin of these peculiar beds, which are full of the debris of Secondary and older rocks transported from great distances northward, see a paper by Sir Charles Lyell, in the London and Edin. Phil. Mag. for May 1840. Also a paper by Mr. Trimmer on "The Geology of Norfolk," containing an account of this and of several other forms of drift, in the Journ. Roy. Agric. Society, Vol. VII. part 2.

out, above that of the surface of the country in which the wells are placed. On this point depends the level to which the water in the Artesian wells may ascend.

As the country rises on both sides from the Thames to the edge of the chalk escarpments, and as the outcrop of the Lower Tertiary strata is intermediate between these escarpments and the Thames, it follows that the outcrop of these lower beds must, in all cases, be on a higher level than the Thames itself, where it flows through the centre of the Tertiary district. Its altitude is, of course, very variable, as shown in the following list of its *approximate* height above Trinity high-water-mark at London.* These heights are taken where the Tertiaries are at their lowest level in the several localities mentioned.

South of London.		Feet	North of London.		Feet
Croydon..............	about	130	Hertford	about	200
Leatherhead..........	„	90	Watford	„	170
Guildford	„	96	Slough	„	60
Old Basing	„	250	Reading	„	120
Near Hungerford......	„	360	Newbury	„	236

Eastward of London these strata crop out on the whole at a gradually decreasing level, but exact data are wanting.

In consequence, therefore, of the outcrop of the water-bearing strata being thus much above the surface of the central Tertiary district bordering the Thames, the water in these strata beneath London tended originally to rise above that surface.

As, however, these beds crop out on a level with the Thames immediately east of the city between Deptford, Blackwall, and Bow, the water, having this natural issue so

* High-water-mark, Trinity Standard (1800), at the Shadwell entrance of the London Docks, is 2·0361 above Sheerness spring high-water, or 19·6699 feet above spring low-water mark of the sea at Sheerness (Lloyd, Phil. Trans. 1831).

near, could never have risen in London much above the level of the river (see § 15).

At Waltham Abbey and Edmonton, as well as at Merton and Tooting, the Artesian wells still overflow; but at London, owing to disturbances in the strata, and the great increase in the number of these wells, the water does not now rise to within a distance varying from about forty to sixty feet below the river-level.

37. *The fifth question relates to the quantity of rain falling in the district in which the water-bearing strata crop out.* This varies materially, and must be calculated separately for each water-gathering district. A term of not less than ten or twenty years should be taken, as the difference in the rain-fall from one year to another, is sometimes very great. The proportion between the fall in summer and winter should also be noted.

The mean annual fall at London, according to observations at the Greenwich Observatory, and those of Mr. Howard at Stratford, &c. (¶ 99), for a period of thirty-four years, appears to average about 24½ inches, which is equal to rather more than 354 million gallons annually, or 970,758 gallons daily, on each square mile.

A certain proportion of this fall, dependent upon the conditions laid down in the second and third questions, passes into the water-bearing strata; in addition to which those beds may also receive part of the rain thrown off by adjacent impervious surfaces (see ¶ 94—6 and §11, for a fuller discussion of this question).

38. *The sixth question relates to the disturbances which may have affected the strata;* for whatever may be the absorbent power of the strata, the yield of water will be more or less diminished, wherever the channels of communication have suffered break or fracture.

If the strata remained continuous and unbroken, we should

merely have to ascertain the fall of rain, and the dimensions and lithological character of the strata, in order to determine their water value. But if the continuity of the strata be broken, the interference with the subterranean transmission of water will be proportionate to the extent of the disturbance.*

Although the Tertiary formations around London have probably suffered less from the action of disturbing forces than the strata of any other district of the same extent in England, yet they nevertheless now exhibit considerable alterations from their original position.

The principal change has been that which, by elevation of the sides, or depression of the centre of the district, gave the Tertiary deposits their present trough-shaped form.† If no further change had taken place we might have expected to find an uninterrupted communication in the lower Tertiary strata, from their northern outcrop at Hertford to their southern outcrop at Croydon, as well as from Newbury on the west to the sea on the east; and the entire length of 260 miles of outcrop would have contributed to the general supply of water at the centre.

39. But this is far from being the case; several disturbing causes have deranged the regularity of original structure. The principal one has produced a low axis of elevation, or rather a line of flexure, running east and west, following nearly the course of the Thames from the Nore to Deptford, and apparently continued thence to beyond Windsor. It

* The term *disturbance*, as used in Geology, refers to the effect of that subterranean power, which, acting upon the crust of the earth, has produced those elevations of the strata, varying from narrow hill ridges to chains of mountains,—or, even where the country is at present apparently level, has left, in the fractures and contortions of the strata, beneath the surface, evidence of its action. Sometimes, although the disjointed parts may remain nearly horizontal, yet each part will be on different levels; at other times, the strata assume a roof or saddle-shaped position. (See ¶ 50 and 118).

† Assuming it not to be the result of original deposition.

brings up the chalk at Cliff, Purfleet, Woolwich, and Loampit hill, to varied but moderate elevations above the river level. Between Lewisham and Deptford the chalk disappears below the Tertiary series, and does not again come to the surface till we reach the neighbourhood of Windsor* and Maidenhead (see Map).

The rise of the Lower Tertiary beds from beneath the London clay, in the railway section at and immediately south of New Cross, exhibits a transverse section of this line of disturbance. Thence to Windsor it is apparently not continuous, and can be traced only in sections of wells, which show that the chalk along this line comes at intervals nearer to the surface than it does either to the north, or to the south, of the presumed axis.

This disturbance has an important bearing upon the supply of water to the Artesian wells of London, and may materially interfere with and diminish the supply from the southern outcrop of the Lower Tertiary strata.

40. There is also, probably, another line of disturbance running between some points north and south, and intersecting the first line at Deptford. It passes apparently near Beckenham and Lewisham, and then, crossing the Thames near Deptford, continues up a part, if not along the whole length, of the Valley of the Lea towards Hoddesdon. This disturbance appears in some places to have resulted in a fracture or a "fault" in the strata, placing the beds on the east of it on a higher level than those on the west, and at other places merely to have produced a curvature in the strata. I am unable, however, to give its exact course or structure, which requires further examination. Its effect, at all events, upon the supply of water to London is important, as in conjunction with the first, or "Thames valley"

* Windsor Castle stands upon chalk, although apparently in the midst of a Tertiary district.

disturbance, it cuts off the supplies from *the whole of Kent*, and interferes, I conceive, most materially with the supply *from Essex;* for in its course up the Valley of the Lea it either brings up the lower Tertiary strata to the surface, as at Stratford and Bow, or else, as further up the valley, it raises them to within forty to sixty feet of the surface.

41. The Tertiary district thus appears, on a general view, to be divided naturally into four portions, by lines running nearly east and west, and north and south, the former line passing immediately south, and the latter east, of London, which stands at the south-east corner of the north-western division, and consequently it must not be viewed as the centre of one large and unbroken area so far as the Tertiary strata are concerned (See Map).*

* There are so few natural sections in the Tertiary district, that it is extremely difficult to trace lines of fault, or disturbance, except where the chalk has been brought by them to the surface. The lines mentioned in the text approximate, I believe, to the truth; still they must be received as uncertain. Of the course of the "Thames valley" line, the proofs are tolerably conclusive, but of the north and south or "Lea valley" line further evidence of its course beyond Stratford and Deptford is required. There are many minor disturbances, the lines of which it would be difficult to follow. One of these runs parallel with the main east and west line of disturbance, at a distance of about two miles north of it. At Gray's Inn Lane, this disturbance brings the chalk to within about seventy feet of the surface of the Thames at high water, but it does not appear to extend far westward. The smaller faults in the neighbourhood of Deptford, Lewisham, and Greenwich, are very numerous and difficult to be traced. For further particulars of the strata and *faults* in these latter districts, I beg to refer the reader to a paper by the Rev. H. M. De La Condamine in the Quart. Journ. Geol. Soc. Vol. VI. p. 440, 1850.

III.—EXTENT AND STRUCTURE OF THE SEVERAL WATER-BEARING DEPOSITS.

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§ 4. *The Lower Tertiary Strata.*

42. Having discussed the general questions we proceed to their special application, commencing with the Tertiary strata. The lithological structure of this series having been described in illustration of the preceding argument need not be repeated here.

It may be convenient for the purpose of comparison to consider the area covered by these strata in the four separate divisions formed by the intersection on the Map of the two principal lines of disturbance.

The north-eastern division embraces generally the district north of the Thames and east of the river Lea, and includes the whole of Essex and part of Suffolk and Herts. The south-eastern forms a district east of the Ravensbourne and south of the Thames, including nearly all North Kent. The north-western division, — the district west of the river Lea and north of a line drawn from New-Cross to Windsor, including Middlesex, the greater part of Herts, and part of Bucks and Berks. The south-western division,—the district south of the latter line and west of the valley of the Ravensbourne, comprising Surrey and part of Berks and Hants. As these districts agree to a great extent with physical divisions on the surface, they can be readily borne in mind. (See Map and explanation of Map.)

43. *North-Eastern Division.*—This division occupies a much larger area than the others. The northern outcrop of

its water-bearing Lower Tertiary strata (*b*) extends about seventy-two miles, from Hoddesdon to Woodbridge. Its position is, as before mentioned (¶ 31), most unfavourable for a water-gathering surface, being placed along nearly its whole length on the sides and slopes of hills, and covered, to a very great extent, by beds of impervious drift. There is, however, another outcrop on the south of this division, ranging along the Thames from Stratford to East Tilbury, on which line the lower sands are of considerable thickness, and are only partially covered by beds of gravel, generally permeable. This zone of outcrop receives little or no drainage from the adjoining districts, all its supply being derived from the rain-water which falls on its own surface. The supply of water in this division by means of overflowing Artesian wells, a considerable number of which have been sunk, is usually small in quantity, rarely exceeding a few gallons per minute, and sometimes even less than a gallon, but it is steady; and in the low marshy islands at the mouth of the Thames (where formerly, in warm summer weather, fresh water was very scarce) a constant and regular supply is now afforded at all seasons by means of them.*

44. Nothing can better illustrate the value and peculiar character of the Artesian system than the efficiency of the borings in these situations,—in the midst of extensive levels with their stagnant and frequently brackish waters bordering the sea, from which many of them have been reclaimed. Be-

* In the Third vol. Proc. Geol. Soc., p. 131, is a short paper by Dr. Mitchell, "On the wells found by digging and boring in the gravel and London clay, in Essex; and on the geological phenomena disclosed by them," in which will be found several sections of wells mentioned in the text, and of others besides.

From the depth of the wells in this district, the pressure of the water on the under surface of the London clay is very great. At the base of the London clay large tabular masses of Septaria are common. This is known as the "water-rock," and as soon as it is tapped the water rushes up with great force and will fill the well, although it may be very deep, in a few minutes. So great is the force exerted that sometimes the water has been known, when shafts are sunk, to *blow up* five feet of the clay, before the works have reached the spring.

fore the introduction of Artesian wells* these districts used to suffer much from the want of fresh water, being entirely dependent upon that supplied by rain.

In the higher and more northern parts of Essex the water in the wells rises very considerably above the level of the Thames, but does not overflow on the surface.

The following are the dimensions of the Lower Tertiary strata in this division of the Map:—

Total extent of Tertiary area	. . . .	1524 square miles.
Lower Tertiary strata—extent of area	. . .	64 " "
" " length of outcrop	. . .	95 miles.
" " thickness of permeable portions		36 feet.

45. *South Eastern Division.*—The second or south-eastern division contributes even less than the preceding one to the supply of London with water.

The Artesian wells of Sheppey and adjacent parts of Kent are sunk in detached and isolated masses of the London clay, but as they do not at all affect the supply of water to London, a description of them may be omitted here, although the phenomena they present is often of considerable local interest.

The space occupied by the outcrop of the Lower Tertiary strata in this south-eastern division is very much larger than in any other. At its western side it approaches very near

* The following list shows the depth, on Dr. Mitchell's authority, of some of the Artesian wells in Essex:—

Name of Place.	Average depth of the wells in Feet.	
Foulness Island	450	All these wells overflow and yield, on an average, from about one to eight gallons per minute.
Mersea and adjoining Islands.	300	
Wallis Island	400	
Little Wigborough..........	250	
Woodham	350	
North Ockenden............	80	
Fobbing	100	
Bulpham Fen	70 to 80	

to London, but as its sand and pebble beds are superimposed upon a base of chalk, and intersected by numerous valleys, the water absorbed on the surface of the hills finds an outlet on the sides of these intersecting valleys, and is thence carried off in the streams which flow to the Thames (see fig. 12, p. 34). It is possible, however, that the Tertiary strata in the neighbourhood of Southend, Bromley, and Beckenham, more immediately south-west of London, and which appear to dip under the London clay of the Norwood hills, may furnish some water to the London wells. There is, however, no evidence to show how far the north and south line of disturbance alluded to above (¶ 40) may interfere with its transmission.

The following are the dimensions of this division :—

Total extent of Tertiary area . . .			325 square miles.
Lower Tertiary strata—extent of area . . .			195 „ „
„	„	length of outcrop . .	65 miles.
„	„	thickness of the permeable portions	72 feet.

It will be observed that in this south-eastern division the extent of exposed surface occupied by the Lower Tertiary strata forms a very large proportion of the whole, and that the water-bearing strata are of greater thickness than in any of the other divisions; but all these favourable conditions are rendered nugatory by its peculiar geological structure.

46. *South-Western Division.*—This division is that in which the water-bearing strata crop out under the most favourable conditions, but their diminished thickness, as compared with that of the same beds in the south-eastern division, materially reduces their capacity for water; nevertheless this district is of far greater importance with regard to the water-supply of London than that of the preceding divisions.

Its dimensions are as follows :—

Total extent of Tertiary area		741	square miles.
Lower Tertiary strata—extent of area		45	,, ,,
,, ,,	length of outcrop	130	miles.
,, ,,	thickness of the permeable portions	22	feet.

If a line to intersect this division be drawn from midway on its eastern boundary, to as far west as Kingston, it will traverse a tract of country in which, allowing for the undulations of the surface, I believe the water in the Artesian wells will be found to rise almost invariably to a height above that of high-water at London. At the same time there are places further westward where the mottled clays so predominate, and the sands are so thin, that deep wells have been sunk without succeeding in obtaining any water at all.*

47. As a general rule, however, considerable supplies of water are to be procured throughout the eastern portions of this district by means of Artesian wells. I would especially refer to the Valley of the Wandle, between Wandsworth and Mitcham. In the village of Garrett alone there are now four or five Artesian wells, all in good and effective condition. The one at the copper mills was sunk several years since. Its depth is 122 feet, and the water has continued to overflow ever since its first issue. At a later period another well has been bored in the street of the village. The water rises several (five to ten) feet above the surface of the ground, and in quantity sufficient to supply the houses around. There is a third such well on some premises adjacent to the village, and lately another has been made in the same neighbourhood, at the New Almshouses belonging to the parish of St. Clement Danes. Although on rather higher ground, the water flows some feet above the

* As at Cobham, to a depth of about 412 feet; at Sandgate, near Chertsey, about 600 feet (?); and at Knap Hill, near Woking, 480 feet. All these wells traversed the London clay, and reached the Lower Tertiary strata, but owing to the great development of the mottled clays no water was found.

surface, and is laid on to all the ground-floors of the forty-two surrounding dwellings, which it entirely supplies; whilst the spare water forms a small fountain in the garden in front. (See also ¶ 52).

At Tooting, Merton, and Mitcham, Artesian wells are also common, and the total supply of water is large, although there is a sinking from the level to which the water originally rose:* yet it rises even now several feet above the level of the Wandle, and in quantities, as I was informed, varying at different wells from 50 to 160 gallons per minute. This, however, requires to be determined by experiment.

With regard to the underground flow of water from this south-western division to the north-western one, as the line of disturbance between New Cross near Deptford and Windsor has apparently produced but little effect, the continuity of the strata is only very partially, and at intervals, interfered with by it. But some impediment to the free subterranean passage of water from one division to the other is, on the whole, caused by it, and this is apparently greatest in the vicinity of London, decreasing as we proceed westward.

48. *North-Western Division.*—It is at the south-eastern angle of this division that London is situated.

The following are its dimensions :—

Total extent of Tertiary area	. . .	345 square miles.
Lower Tertiary strata—extent of area	. . .	50 " "
" "	length of the outcrop .	60 miles.
" "	thickness of permeable portions	15 feet.

In the Hertfordshire part of this division the water-bearing strata are tolerably well developed; but in Buckinghamshire, the mottled clay-beds largely predominate, and materially

* This, however, arises not only from multiplying the wells too much in any one locality; but also from defective construction, and from the tubes becoming obstructed by sand.

interfere with the water-value of the strata, which is further diminished by the unfavourable position (midway on the slopes of the hills) of the outcrop of the Lower Tertiary series. This district is covered generally, both on the hills and in the valleys, by thick beds of gravel and brick-earth; and although these are, to a certain extent, permeable, yet by retarding the passage of water from the surface, they must lessen the quantity which would otherwise be absorbed by the Lower Tertiary strata.

The main sources, therefore, from which the supplies in this division are derived, are the small transverse valleys and openings, which, running from the chalk district southward into the Tertiary series, expose at their base, and on lower levels, a greater extent of the water-bearing strata, (¶ 31).

This supply of water, limited as it is, is not transmitted without interruption to the Lower Tertiary strata beneath London. As far as the obscure character of the surface and absence of sections will allow me to judge, a slight disturbance in the form of a ridge or flexure of small elevation runs north-east and south-west through Northaw in Hertfordshire, where it raises the chalk to the surface considerably within the boundaries of the Tertiary district. It passes thence under the hills between Potters Bar and Barnet, bringing up there the lower beds of the London clay in the tunnel on the line of the Great Northern Railway.

As this disturbance raises the chalk at Northaw apparently to nearly the same elevation as it is at its outcrop from Hatfield to Hertford, it must there form a barrier stopping the water received by the Lower Tertiary strata along that line of outcrop in its flow towards London (see Section 1).

The rise of the chalk so near to the surface at Pinner and Ruislip would there again interfere with the transmission of water.

In consequence of these disturbances, and of the high level

of the chalk in the district between its outcrop in Hertfordshire and the north-west of London, the quantity of water found in the sands is small in comparison with the yield in the districts north-east of London, nor does it rise to within a considerable distance of the general surface.

It is in the valley of the Thames from Maidenhead to Windsor, that of the Colne near Uxbridge, and of the Lea at Hoddesdon, that the largest breadths of the Lower Tertiary strata are exposed in this north-west division, and where the drainage received from adjacent tracts is the greatest.

In the western portions of this division the supply of water derived from the Lower Tertiary strata is limited and uncertain. In the extreme eastern portions it is much more abundant. In the Valley of the Lea from the north-east of London to Broxbourne, Artesian wells are numerous, there being as many as eight or ten (if not more) at and near Waltham Abbey, three or four at Edmonton, and several at Tottenham. They are generally about 80 to 100 feet deep, and yield a steady supply of from two to eight gallons of water per minute, overflowing one to three feet above the surface.

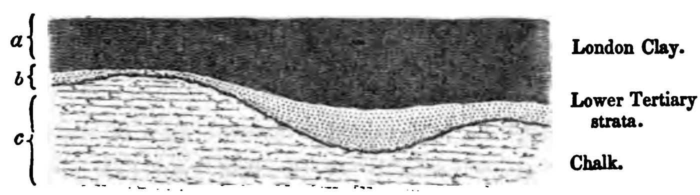
49. Let us pass from the outcrop of the strata to their position beneath London, where the numerous wells sunk of late years have afforded many opportunities of ascertaining the depth and thickness of the London clay, and of the sands and clays between that deposit and the chalk.

It is now perfectly well known that the upper surface of the chalk underneath London is very irregular.* This has

* A Paper on the inequalities of the surface of the chalk beneath London was read two or three years since before the Institution of Civil Engineers by Mr. Braithwaite, and two sections traversing London are given by the same author in the Proc. of the Inst. Civ. Eng. 1850, Vol. IX. Mr. R. Mylne's paper before referred to also shows, in a series of sections, the inequalities and depth to the chalk, and the thickness of the Tertiary strata, beneath London. The topographical map of Mr. Mylne is a valuable illustration of superficial areas occupied by these strata at London.

been frequently attributed to denudation of the chalk before the commencement of the Tertiary period, whereby hills and valleys similar to those of the existing surface of the land were formed; and it has been inferred that these irregularities were afterwards filled up by the Tertiary strata. I do not quite agree in this view, although it is a condition which may exist to a certain extent. The chalk has no doubt been extensively denuded, but still I have never seen in any length of exposed sections of the junction beds of the chalk and Tertiaries more than slight irregularities of the surface of the former, nor have I observed sufficient variation in the thickness of the mass of the Lower Tertiary strata to conclude that, at the commencement of the Tertiary period, the surface of the chalk was as varied as that of the present land. For, on the assumption that the chalk presented originally a surface of variable level, it would follow that the first series of sedimen-

Fig. 15.

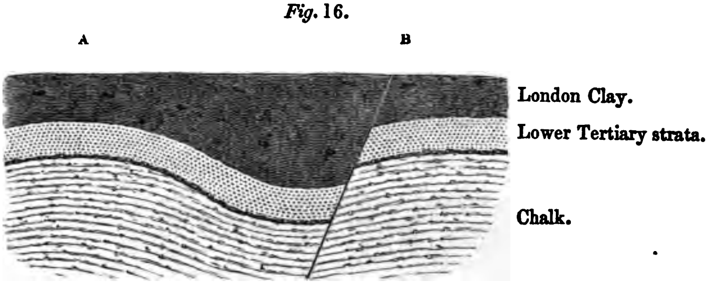


tary deposits spread over such a surface, would tend to fill up, and gradually to lessen and efface, these inequalities. Consequently the thickness of the strata at first deposited on the chalk, would vary in some measure according to the difference between the height of these ancient hills and the depths of the intersecting valleys (as shown in Fig. 15); so that they would be in some places very thick, and in others often almost wanting, and the London clay would repose immediately or nearly so upon the chalk. But such a result is exhibited only to a limited extent in the Lower Tertiary strata.

There can be no doubt that there were irregularities in the deposition of the Lower Tertiaries; and that the erosion, previously to their accumulation, of the surface of the chalk, which was evidently very great, may have led to some variation in their thickness ; but the chief cause of the great difference of level in the surface of the chalk underneath London, must be sought for in physical changes posterior to the formation of the Tertiary strata.

50. These changes may have been effected either by elevation (as at A in fig. 16), or by fracture (as at B), causing differences, as great in one case as in the other, in the level of the chalk, whilst the ordinary thickness of the Lower Tertiary strata would be maintained. Several lines of disturbance, most of them probably of the first kind (A), appear to traverse the Tertiary strata at and around London, and generally to follow an east and west direction parallel to the main " Thames valley " axis of elevation or flexure ; and although none of them are on a large scale, they all interfere more or less with the passage of water through these strata.

Fig. 16.



This peculiar irregularity of surface can be best understood by reference to actual sections, such as those of Mr. R. Mylne, where all the phenomena are remarkably well depicted.

51. It would seem therefore that, notwithstanding the great length of the outcrop of the Lower Tertiary strata in the counties around London, only a very limited portion of it can contribute in any extent to the water supply of the

Artesian wells at London. The Essex, or north-eastern division, furnishes but little. The Kent, or south-eastern division, is probably even of less assistance; and it is consequently from some few portions of the two western divisions that the bulk of the water seems to be derived:—

1st,—from the outcrop of the Lower Tertiary strata, in parts of the valley of the Lea.

2nd,—from some portion of the outcrop of the same beds, in the north-west of Middlesex.

3rd,—and mainly, from their outcrop in East Surrey.

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52. Of what may now be the actual quantity of water furnished by the Lower Tertiary sands it is difficult to form even an approximate estimate.*

In the absence of more exact data for determining this point, I can merely hazard a few general calculations, taking minimum quantities. In the first place, the Valley of the Wandle from Wandsworth to Merton and Mitcham, presents us with the most accessible and best data in that district. Many of the wells yielded originally from 150 to 200 gallons per minute, but the quantity is now (owing to various causes) generally less.† In the second place, in the valley of the Lea between Clapton, Waltham Abbey, and Broxbourne, there are a number of Artesian wells; those at Waltham Abbey yielding, as we have just mentioned (p. 50), from two to eight

* For an account of the former yield of some of the early Artesian wells around London, see the work beforementioned (p. 10), of M. Hericart de Thury.

† At Mr. Shears' copper mill at Merton, the water rose originally thirty feet above the surface; and the yield at a height of three or four feet, was found to be 200 gallons per minute. This, I believe, was the largest result obtained in this district. When I saw the well in June 1850, I could not, owing to the distribution of the water in several channels, ascertain its exact yield. It was supposed to be about 100 gallons per minute.

At the copper mill at Garrett the yield at the surface exceeded 120 gallons per minute, and continues without apparent decrease.

gallons per minute. At London and the neighbourhood (westward), where the water does not rise to the surface, there are no sufficient opportunities of ascertaining the supply.

These remarks have reference only to the wells which derive their supplies from the Lower Tertiary sands. In the valley of the Wandle there are few or no exceptional cases.* In the valley of the Lea, on the contrary, many wells are carried down into the chalk. These are excluded in the following, which is a very rough, and, I believe, low estimate of the quantity of water which these strata may be supposed to yield in two given districts of limited dimensions; assuming, on a moderate calculation, that there are about fifteen to twenty Artesian wells in the valley of the Wandle, and about twenty to thirty in the valley of the Lea.

		Daily Supply.
Valley of the Wandle . .	from	800,000 to 1,200,000 gals.
Do. of the Lea . .	„	120,000 „ 200,000 „

The preceding observations have, however, reference only to those districts in which the water overflows at the surface, and which constitute but a small portion of the area over which the Lower Tertiary strata extend. Elsewhere, however, within this area, where the ground is higher, the water does not rise to the surface, and the wells, although numerous, are no longer so conspicuous.†

53. If, taking the country westward of the meridian of Greenwich, a line be drawn passing about nine miles south, 18 to 20 miles west, and 14 to 15 miles north, of St. Paul's, it

* At Mitcham, Mr. Nightingale has, however, recently sunk one through 190 feet of Tertiary strata, to a depth of 21 feet in the chalk, and has obtained a large jet of limpid and excellent water, rising several feet above the surface of the ground, and which supplies his dye works, his neighbours, and forms a fountain besides. This case is remarkable for the height to which the water from the chalk rises.

† I consider all these wells as "Artesian." The same principle of compression of the water by an impermeable mass of strata below the level it would naturally take, is applicable to all; although the variable level of the surface of the ground, and local exhaustion of the strata, limit the overflow to a few localities only.

will include a tract in which, with few exceptions, the Lower Tertiary strata are water-bearing, and in many parts of which they serve commonly as sources of water supply. In London itself the supply from the sands is no doubt considerable, but the wells are so numerous both in this deposit and in the chalk, and the exhaustion, consequent on the large demand, so great, that it has, I believe, led to an intercommunication of the waters from these two sources, such as would render it almost impossible to assign to each the relative proportion which it contributes to the water supply,—or rather to determine how much of the water found in the chalk belongs properly to that deposit, and how much of it is derived from the overlying Tertiary sands.* There are still, however, a considerable number of wells in the sands drawing a supply of from 10 to 50 gallons per minute.†

Including, however, the whole of this area, we may safely calculate that the number of the principal deep wells deriving their supplies from the Tertiary sands is not less than 250 to 300.‡

* The Tertiary sands having, of late especially, been often found to yield an insufficient quantity of water, it has become usual, when larger supplies are required, to carry down the wells into the chalk. The result is generally, but not always, favourable. The water from the sands is sometimes admitted in addition to that from the chalk, at other times and more commonly the water from the Tertiary strata is shut out, and excluded from the well.

† It is rarely that we are furnished with any statement of the products of the two deposits in one shaft. Mr. Robert Davison has, however, given some exact information on this point, though, of course, no comparative estimate can be derived from a single case. He states that in sinking the well at Messrs. Truman, Hanbury and Co.'s, an abundant supply of water was obtained in the Lower Tertiary sands at a depth of 135 feet. At 200 feet the chalk was reached, and the well was continued in it to a further depth of about 200 feet. By means of iron cylinders pierced at intervals, the water from the sand was allowed to flow into the well. The result was that 4,860 gallons of water per hour were obtained. Of which quantity, as well as I can make the numbers agree, 2,880 gallons came from the Tertiary sands, and 1,980 gallons from the chalk (see Min. of Proc. Inst. Civ. Eng. 1842). Since this period, however, the exhaustion of these sands has greatly increased.

At the well on the Lower Heath, Hampstead, 70 gallons per minute are pumped up continuously,—of which 60 gallons are from the sands, and 10 gallons from the chalk. The first 40 feet of the latter yielded no water.

‡ The number, however, is probably much greater than this.

The delivery of water from those wells which do not overflow, will of course be very much less than at those where a constant flow above the surface is going on; but as the ordinary wells are so numerous, and there are other overflowing wells than those enumerated above, I do not think that, taking the whole of them into account, we shall exceed the bounds of probability in estimating the yield of water from this group of strata, within the area just defined, at 3,000,000 to 4,000,000 gallons daily. Whilst if, as there are grounds to believe, much of the water derived from the upper beds of the chalk beneath London is supplied by infiltration from the overlying sands, then this estimate of the quantity of water yielded by this source must be very considerably increased. (For inquiries bearing on this point, and for some account of the character of the waters from the Lower Tertiary strata, see Appendix C.)

§ 5. *The Chalk.*

54. From the large extent of country occupied by the Chalk formation in the counties around London, from the breadth of its denuded surface, its great porosity and absorbent power, and the number and abundance of its springs, peculiar interest attaches to it as a source of water supply. The question presents so many conflicting facts that it has given rise to much diversity of opinion upon some of the more theoretical points.*

* It has been made the subject of inquiry and research on the part both of engineers and geologists ;—

With regard to the large supplies unquestionably often obtained from the Chalk where it *forms the surface of the country*, Mr. Robert Stephenson, in his "Reports to the Directors of the London, Westminster, and Metropolitan Water Company," in 1840 and 1841, mentions amongst a number of other localities, at which the quantity of water has been distinctly ascertained—the Tring cutting of the North Western Railway, where, notwithstanding the height of the ground, the yield of water amounted to upwards of 1,000,000 of gallons per day ; Winchester, where a well in the chalk supplies 31,680 gallons per 12 hours ; Arundel, where a shallow well in the chalk in the lower part of the town, and a spring in the chalk, in the upper part, supply nearly the whole town. At Brighton, from a well at the water-works, 97 feet deep, an engine of twenty-nine horse power lifts 231,840 gallons per 12 hours, and no complaints of want of water in the older wells in the town have arisen. At Dover the supply is nearly as large. At Deal, Ramsgate, Gravesend, and St. Albans, the supply is also large and abundant. Twelve hours' pumping reduces the level of the water in these different towns, from two to ten feet, but it is speedily restored. The report also expresses views favourable to deriving, at Watford, large supplies of water from the chalk—as much or more than 8,000,000 gallons per diem, by means of works to proper depths, and sufficient driftways. With reference to underground springs Mr. Stephenson considered that the "plastic clay sands," are supplied with water chiefly through the medium of the chalk, which latter is the "great water-bearing stratum," "from which all the Artesian wells beneath London, directly or indirectly, draw their supplies." In a discussion, however, in 1849, on the subject of the Artesian wells in London, he stated his opinion that these sources (from the sands and the chalk in their subterranean position) would not be at all adequate to the water-supply of the Metropolis. (Meeting of Inst. Brit. Architects, Nov. 1849.)

Mr. S. C. Homersham, in his "London and Watford Spring-water Company Report" (1850), is of opinion, "that from the deep springs of the Chalk formation an enormous amount of water may be easily and cheaply obtained ;" and states that the

As this formation cannot, however, like one composed of arenaceous strata, be considered as truly permeable, an exact

experimental well in the Bushey meadows actually yielded 1,800,000 gallons per day. He gives a number of calculations relative to the superficial area of the chalk, and estimates the quantity of rain falling upon it, in the South of England, to amount to 1,595,000,000 gallons per day. The area of the chalk sloping towards Watford he calculates at 1200 square miles, receiving a daily mean supply of rain-water, equal to 408,000,000 gallons, and that at present the water finds a vent, and is discharged along the sea coast. He states that there are large fissures or cavities in the chalk, from one to twelve feet in depth, and containing large quantities of water, and instances the powerful springs of Amwell and Chadwell, as issuing from such interstices and fissures. The greater part of the rain-water falling on the chalk, he thinks, however, descends through fissures, "until arrested by the bed of gault clay lying beneath the chalk." He is further of opinion that even a much larger quantity than 8,000,000 gallons per day, "might with facility be procured by a well or wells with adits, in the chalk under Bushey meadows, from a very small area," and that the source from which this water is obtained will not diminish in its yield. He observes also "that this water is remarkably free from organic matter,—at all times perfectly pellucid,—and when collected, and allowed to remain for a short time in reservoirs suitable for distribution, is as soft or softer than the Thames water." He gives in an appendix, a variety of information connected with the quality and analysis of different waters.

A plan has lately been suggested by Mr. P. W. Barlow for collecting the water which he proves to abound in many of the chalk valleys in Kent; to intercept, in fact, by means which cannot be described here, a portion of the large quantity of water, —received by the exposed surface of the chalk in Kent,—as it passes down to the lower levels along the Thames. The quantity of water in some of these springs he has shown to be very considerable (Report to the Directors of the South-Eastern Railway, 1850).

The preceding observations have reference chiefly to wells at the *exposed surface of the chalk;* those which follow relate to the Artesian wells which are sunk, *through the overlying Tertiary strata,* into the chalk.

Dr. Buckland has frequently pointed out that the height of the water in the Artesian wells at London diminishes as the number of wells increases, to prove that the limits of the supply are already exceeded. (Bridgewater Treatise, 1836, p. 564, and elsewhere subsequently.)

The Rev. J. C. Clutterbuck states, that the Artesian wells in the chalk around London, are being exhausted more rapidly than supplied. From a series of very careful experiments on the level of the springs in the chalk, he estimates the general permanent depression of the water-level beneath London to be from 50 to 60 feet below Trinity high-water-mark (Proc. Inst. Civ. Eng. for 1842–3 and 1850).

Mr. R. Mylne, in the third volume of the Trans. Civ. Eng. 1840, p. 229, makes some general observations on the sand and chalk wells in London, with reference, however, more particularly to the former. Mr. J. Simpson, in his observations on this paper, observed upon the number of Artesian wells of London in the chalk, and considered that large supplies might be derived from this source, by means of properly constructed works, and that its capabilities had not yet been fully developed.

Mr. Robert Davison thinks the water to be obtained from the chalk more precarious

comparison between it and the Lower Tertiaries and Greensands, which afford more definite and positive data for calculating their water value, cannot be established. I will therefore examine its conditions of water supply by themselves, and as briefly as the nature of the subject will allow.

55. The chalk not only forms a broad belt at a short distance around London, but also passes under the city at a depth not exceeding 150 to 250 feet; it might, therefore, if all the conditions were favourable, transmit a very large quantity of water from its exposed surfaces to these deep-seated portions underlying the Tertiary strata,—to be there available by means of Artesian wells.

Taking the whole of the chalk district surrounding the Tertiary tracts of Kent and Surrey, along with that portion in Hampshire and Wilts which lies north of a line drawn from Alton to Devizes,—of Berkshire, Oxfordshire, Buckinghamshire, Hertfordshire, Essex, Bedfordshire, Cambridgeshire, and of Suffolk, as far north as a line drawn from Newmarket to Woodbridge,—it forms an area of about 3794 square miles,

than from other springs. Still, when crevices exist, it flows in large quantities (Min. of Proc. Inst. Civ. Engineers, p. 192, 1842). For various other opinions on this subject I would further refer to the discussions at the Institutes of Civil Engineers and British Architects, on the papers of Dr. Buckland, in 1842 and 1849, as well as to those on the papers abovementioned of the Rev. Mr. Clutterbuck.

The capabilities of the chalk as a source of deep water-supply have been maintained by Mr. J. L. Tabberner, who states that the quantity already supplied by the different deep wells (almost all in the chalk) in and around London amounts to 10,000,000 gallons daily, and considers that it might be increased to 50,000,000 gallons daily. He recommends that the wells should be sunk deeper into the chalk. (Letters to the Daily News, 13th and 15th March, 1850, and since republished by Renshaw).

Sir W. Clay considers the objections to Artesian wells (those in the chalk and Tertiaries) as insuperable, on the grounds of insufficiency of supply, and uncertainty of quality, "Remarks on the Water supply of London, 1849." Second Edition, p. 39:—a pamphlet containing much important information respecting the existing Water Companies.

Mr. Seaward also objects strongly to Artesian wells for public supplies (Trans. Civ. Eng. Vol. I. p. 145.

Since these pages were written the question of the supply derivable from the chalk, has been discussed at length by Prof. Ansted in his Treatise on Geology (see p. 74).

on which the mean daily fall of rain is probably not less than 3800 to 3900 million gallons (see Map).

56. It is evident from the absence both of streams and also of standing waters on the surface, that a very large portion of the rain falling on a *bare* chalk district (as on the Downs of Epsom, Banstead, and the South Downs in general), infiltrates at once into the ground; but what proportion of it is absorbed by the surface chalk or is returned again to the atmosphere by evaporation and by vegetation, and what proportion passes into the interior of the deposit to add to the springs, has yet to be determined.

Over large districts in Essex, Hertfordshire, Buckinghamshire, Oxfordshire, Berkshire, and to a lesser extent over Surrey and Kent, the chalk, however, is not bare, but is covered by an impermeable bed of a ferruginous drift clay, 10 to 20 feet thick, impeding almost invariably the passage of the surface water into the chalk below. This clay, however, rarely exists in any extent except on the higher grounds.* The sides and bottoms of the valleys, and a large portion of the hills, are generally free from impermeable drift; and the former receive not only the rain-water falling immediately upon their surface, but also a portion of that which is thrown off by the clay drift, where it covers the adjacent hills.

It is to be observed also that there are several outliers of Tertiary strata of some extent (omitted generally in the Map) which further reduce the area of bare chalk.

57. That the chalk is porous, and will imbibe a large quantity of water is certain (see note p. 74); but its texture is too fine and close to allow water to pass freely through it. I have found by experiment that a piece of chalk† two inches thick, and containing 63 cubic inches, absorbed 12 cubic inches of water in one minute, 20 cubic inches in five minutes, and became

* The gravel in the valleys in these districts is far more permeable.

† From the middle chalk, Ware.

fully saturated with 26 inches in 15 minutes. Nevertheless when left to drain for 12 hours, this specimen yielded only $\frac{1}{10}$th cubic inch of water; while the same piece of chalk thus saturated transmitted water so slowly, that in 12 hours, and with 8 square inches of its surface kept covered with half an inch of water, only $\frac{6}{10}$th of an inch filtered through it. Through a mass of siliceous sands* of the same dimensions, and under the same conditions, on the contrary, 320 cubic inches of water passed through in one hour, being equal to 3840 inches in the 12 hours; whilst 63 cubic inches of sand saturated with 22 cubic inches of water, gave off by drainage about four cubic inches in the 12 hours (p. 114).

The surface of the chalk to the depth of several feet beneath the ground is commonly very much broken and fissured in all directions, and into these fissures the rain-water rapidly passes. They decrease in number as the distance from the surface increases, but the larger fissures being continued to greater depths, a certain quantity of free water can pass to the lower portions of the chalk. In these deep-seated beds it is along the unadhering surfaces formed by the planes of stratification† especially that water is transmitted.

Looking, however, at the remarkable rapidity with which chalk imbibes water, the excessively crevised condition of its surface, and its strong retentive power, I apprehend that by far the greater proportion of the rain-fall is arrested in the few feet of chalk immediately beneath the vegetable mould; and that it is only in heavy and long-continued rains that any water finds its way to those low levels, where, from the constant contact of water, the mass of the chalk must be fully saturated, and where, consequently, the water passes through the fissures without any further loss. The mere contact of dry chalk, for a few minutes, with water, sufficing for the

* Specimen No. 11 in table, p. 114.

† The parallel horizontal surfaces dividing the deposit into beds.

absorption of 30 to 40 per cent of moisture, and that without the chalk losing its aspect of apparent dryness, shows how large a proportion of the rain-fall may, if I can so term it, be rendered latent by this strong capillary attraction. The water thus absorbed and held by the surface beds, must be wholly or in greater part returned again to the atmosphere by evaporation direct, and indirectly by means of vegetation.*

58. Where the chalk rises in hills, water does not appear to lodge in it, and it becomes in almost all these cases necessary to sink on the hills to the level of the adjacent valleys before reaching the water level. The position of this line of water-level depends, however, upon a number of conditions such as, slight differences in the lithological character of the strata, their dip (partly), the size and number of the fissures, and the depth and inclination of the valleys. It is also affected by the magnitude of the "massif" of the hills and the distance, in the line of dip, of the lowest valley levels of the district.†

It is evident from the facts cited by Mr. R. Stephenson and others, that the chalk in many parts of its exposed area contains considerable quantities of water, although in some places

* It is probably this strongly absorbent and retentive quality of chalk that renders the bare chalk downs so dry and yet so constantly verdant.

† No rule generally applicable can be laid down with regard to the fall of the line of water-level, in traversing a chalk district at right angles to the range of the strata. It requires, in each case, to be experimentally determined. This has been very carefully done in two distant portions of the chalk area. The first series of observations are those recorded by Mr. W. Bland, Jun., in 1832 (Phil. Mag. new ser. Vol. XI. p. 88), in which he gives tables of the level at which the water stands in the wells along two lines (about six miles apart) traversing the chalk district from near Sittingbourne to near Maidstone in Kent. Reducing these observations I find that on one line the fall of water-level is 330 feet in seven miles, or equal to 47 feet per mile, and on the other 182 feet in four miles, or 45 feet per mile. The Rev. Mr. Clutterbuck, on the contrary, has shown (Proc. Inst. Civ. Eng. 1842-43 and 1850) by accurate measurement and by sections, that in Hertfordshire the average inclination of this level along a line of about 14 miles, from near Dunstable to Watford, is only 13 feet per mile. In one instance Mr. Bland shows that in a distance of rather less than a mile there is a difference in the water-level of 102 feet, and in another of 93 feet in apparently less than a mile: these probably arise from some local cause.

it may be penetrated to great depths, without increasing the supply obtainable nearer to the surface. It is apparently within the first 50 to 100 feet below the level of the valleys of the district, and again in the beds immediately incumbent on the "chalk marl," that the most water is found. The intermediate portions are constantly found without any important quantity of free water.

The deep well at Saffron Walden, in Essex, passed through 1000 feet of chalk before meeting with a sufficient supply of water;* and at Diss it was not until the whole of the chalk was traversed, that water was obtained.

59. The chalk district around London generally rises above the level of the surrounding country; its outer edge or escarpment usually attaining a height of from 400 to 800 feet above the level of the Thames at London, whilst at its point of junction with the Tertiary strata, its average height is from 50 to 200 feet. If the chalk were perfectly permeable, so long as any water remained in it above the level of that portion which is beneath the Tertiary strata, all such water should percolate to that lower level; and the volume of the chalk above that line is so great, that no deficiencies in the supply should, under ordinary circumstances, be experienced. But this is not the case; fissures in the higher levels remain charged with water, whilst other fissures lower down are drained. These channels of communication are too small and few, and the chalk itself is too fine-grained and comparatively impermeable, to transmit readily in its deeper-seated beds any large quantities of water.

60. That it can only be through fissures and not by general permeation in the mass, that water circulates through the chalk, is demonstrated by the fact that if a shaft be sunk into this formation to a depth of, say, 30 feet below the level at

* A supply was obtained at a depth of 300 feet, but not being found sufficient the works were continued to this great depth.

which the water stands, and the water pumped out, it will be replaced by the abstraction of the water in all the communicating fissures, and from a distance dependent upon the size and number of the fissures, the quantity of water taken out, and the resistance to its flow through these narrow channels, but more especially on the *head* of water on or above the level of the point of draught. Consequently the effect is very variable, being sometimes comparatively imperceptible, and at other times extending over very considerable distances. Thus, along the boundary of the Tertiary area, beyond which the whole "massif" of the chalk district rises, the head of water is usually very large, and, provided the chalk be sufficiently fissured, the springs on this line can draw their supplies from all the upland tracts above it, and therefore are the last to be affected by any deficiency in the supply. In the higher chalk districts, however, when the head of water is small, the fissures are soon exhausted. Mr. Bland mentions a well near the centre of the high chalk region between Sittingbourne and Maidstone which was drained dry by emptying another well nearly a mile distant: this latter was 374 feet deep and usually had 52 feet of water in it, and the other was 303 feet deep with 37 feet of water;—the water level stood in the exhausting well only 27 feet below that of the well drained. Now chalk, when fully saturated (as the mass of it below the water level must no doubt be) containing about one third of its volume of water, if it could yield even a small proportion of this large content, a supply of several hundred thousand gallons might have been obtained within a radius of 200 to 300 feet around the shaft; whereas the water contained in the substance of the chalk escaped so excessively slowly, that it had no sensible influence on the supply, and the removal of water at the one point drained off rapidly the free water held in the communicating fissures, to a distance of one or more miles around. This effect will be less

felt at greater depths, where the hydrostatic pressure forces the water through the fissures with greater rapidity, but nevertheless the same rule holds good.

The variation in the facility with which water travels, and in its amount under similar physical conditions, into the Chalk and the Lower Greensand (but at a less surface height in the Tertiary district), are very apparent in the extent of fluctuation of the water-level in these formations at different seasons of the year.

The more equable and sustained power on the part of the arenaceous strata is shown generally in the following table, which is calculated from the observations recorded by Mr. Bland, in the district before mentioned (note p. 62):—

	Number of wells observed.	Average height of water. June. Ft. In.	December. Ft. In.	Differences of level in summer and winter. Ft. In.
Lower Tertiary strata	5	7 5	6 10	0 7
Chalk	15	30 1	23 8	6 3
Lower Greensand	5	3 10	3 7	0 3

61. With reference now more particularly to *the condition of the Chalk underlying the Tertiary strata*. It is evident, in the many movements of elevation and depression which the crust of this part of the earth must have undergone, and in the numerous earthquakes which have taken place since the land has assumed its present form, that those strata which form the immediate surface must have been far more shattered and fissured than those which are covered by a great weight of superincumbent deposits: the one portion would be extensively fissured and crevised, whilst the other would remain comparatively unbroken and entire. Therefore, we cannot expect to find in the deep-seated mass of chalk beneath the Tertiary strata, the same facilities for the transmission of water as those which evidently exist in it where it constitutes the surface of the country. In descending below the surface of the ground the crevised condition of the chalk diminishes—

the vertical fissures become rarer, until in the deep-seated beds beneath the Tertiary series the passage of water takes place almost entirely along the planes of stratification, which are generally marked by layers of flint.*

The depth to which it is necessary to proceed when, owing to a deficiency in the supply of water in the Tertiary sands, the wells have been continued downwards into the underlying chalk, is quite uncertain, sometimes a few feet suffice, at other times 100 to 200 feet have to be traversed before meeting with a sufficient supply, nor does it always increase with the depth—sometimes quite the contrary. Lateral headings or adits are occasionally expedient to drain the fissures over a larger area.†

The same uncertain conditions prevail in the chalk in France. No springs of any consequence were met with in passing through the 1400 feet of that formation at Paris, nor in the 760 feet at Calais (see Appendix A). At Suresne, near Paris, M. Mulot bored 408 feet into the chalk (first passing through 131 feet of Tertiaries), but without success.

* As an instance of this, the well sunk by Mr. Braithwaite, at Reid's Brewery, is illustrative. The first 135 feet passed through Tertiary strata, when the chalk was reached. The diameter of the shaft was here 5 feet 3 inches, by 3 feet 2 inches. From this point downwards the well was gradually enlarged for a depth of 43 feet to 16½ feet in diameter. Water was found under the second, sixth, eighth, and tenth layers of flints. The supply from the eighth layer was the largest, being 10,800 gallons daily. Continuing the work 22 feet deeper, by a seven feet shaft, water was found in two horizontal fissures of the chalk without flints. Three adits were then driven horizontally from the shaft, one 91 feet in length at the depth of 196 feet, and two more at the bottom of the well. By these means 121,600 gallons of water daily, were obtained. This well is, at a later period, stated to yield 277,200 gallons per twenty-four hours, or 192 gallons per minute, and to be 22 feet deeper. (Minutes of Proc. Inst. Civ. Eng. 1842).

In sinking the well at the Hampstead Road reservoir, the principal supply of water is stated by Mr. R. Mylne to come from underneath the layers of flints (Trans. Civ. Eng. vol. III. Part 3). Mr. J. Simpson also notices the supply as being met with in the layers of flints, in fissures, and occasionally in soft veins in the chalk.

† The following are the depths, at various places, to which the chalk had to be penetrated beneath the Tertiary strata before obtaining a sufficient supply of water. Where not mentioned to the contrary, they are on Dr. Mitchell's authority.—

The well was afterwards carried to a depth of 675 feet, and yet no water found. M. Garnier mentions (p. 62 of his work before quoted), that at Bethune an Artesian well was sunk through 60 to 70 feet of Tertiaries, and 30 feet of chalk, when an abundant supply of water was obtained; whilst on the adjoining premises 70 feet of Tertiaries and 105 feet of chalk were traversed without meeting with water.

The mass being comparatively homogeneous, the delivery of water should take place, if it were freely permeable, as soon as the bore has passed through the Tertiaries, or, at all events, water should be found at the same depths within a limited area. This is almost invariably the case in water-bearing sands, from which, as soon as the overlying permeable deposit

Name of Place.	Gravel and Tertiary strata.	Depth in the chalk.	Total Depth.
	FEET.	FEET.	FEET.
Beaumont Green, Herts[a]	126	57	183
Loughton, Essex[b]	324	211	535
Harwich[c]	64	293	357
Epsom.[d]	80	80	160
Thatcham, Berks[e]	100	3	103
Norwood, Middlesex[f]	325	89	414
West India Export Dock[g]	120	240	360
Zoological Gardens, Regent's Park[h]	220	7	227
Reid's Brewery	135	123	258
Barclay & Perkins' Brewery	235	132	367
*Combe & Delafield's Brewery	222	300	522
*Meux and Co.'s Brewery	170	265	435
*North-western Railway Station	230	170	400
†Nicholson's Distillery	140	20	160
†Greenwich Hospital	124	125	249
†Abbott's, Bow	150	272	422

[a] A good spring of water found.

[b] Water was met with in the sands over the chalk, and rose to within 90 feet from the surface; no increase was obtained after boring through 211 feet of chalk.

[c] Work abandoned.

[d] A good supply of water after passing through a layer of flints.

[e] Water rose to surface, 200 gallons per minute.

[f] Unsuccessful at this depth.

[g] No particulars given.

[h] Supplied (1836) 92,859 gallons daily.

* These are taken from Mr. R. Mylne's sections of the London strata.

† Mr. Braithwaite's sections in Min. Inst. Civ. Eng. 1850.

is penetrated, the water at once rises, as for instance at Cambridge where all the Artesian wells terminate immediately at the base of the gault,—at the upper surface of the underlying sands.

62. The lower beds of the chalk are generally so argillaceous, that the rock often puts on the character of an indurated clay, which on exposure to air and water softens into a tenaceous mud. When first exposed, its colour is bluish grey; but it becomes white or nearly so as it dries.*

On the whole, the change of mineral condition, together with the absence of layers of flints, render this lower portion of the chalk very retentive of water. In the district north of London especially, the lower beds attain a great thickness. They everywhere form a generally impermeable mass of strata, between the upper and middle chalk above, and the Upper Greensand below.†

63. With regard to the quantity of water supplied by the chalk beneath London, the wells are so numerous and their yield so varied, that it is difficult to form an estimate. The supply at different wells varies from 10 to 200 gallons per minute. In a few it is rather higher than this, and in one or two rare cases 300 gallons are supplied by constant pumping

* This part of the series, however, occasionally contains some subordinate partially sandy beds, which are then permeable, as may be observed in the neighbourhood of Dunstable and Tring. The following section is given by Mr. W. Gravatt of a well on the line of the Grand Junction Canal near Tring.

	FEET.	
Chalk	20	All these beds belong probably to the lower chalk. When wet and first excavated, they are hard and of a dark bluish grey colour, but disintegrate, and become nearly white by exposure to the atmosphere.
Hard blue clay	30	
Blue stone	4	
Hard blue clay	47	
	101	

At the depth of 54 feet the water rose to the top and ran over 1,300 cubic feet in 24 hours. At the depth of 101 feet no more water was obtained than at 54 feet (Trans. Civ. Eng. 1836, Vol. I. p. 136).

† Along the line of outcrop in Bedfordshire it is very difficult to mark where the chalk marl ends, and the upper greensand commences, or where the latter is divided from the gault. They appear to pass one into the other.

during six days in the week. A considerable number of wells furnish, however, from 70 to 80 gallons per minute.* In 1838 the total supply appears, from some statistical returns, to have amounted to about 6,000,000 per day. The quantity is now estimated at from 10,000,000 to 12,000,000 gallons daily,† which must be, I think, considered as a rather extreme quantity. Much of this water, I also believe, for reasons elsewhere assigned, to be derived from the overlying Tertiary sands.

In Conybeare and Phillip's "Geology of England" the particulars of a well in the east of London, show that in 1821 or 1822 the water from the chalk rose exactly to the level of Trinity high-water mark. The same fact seems to have been noticed also in 1822, in ten other deep wells. Since that period there has been a gradual but variable decrease, on an average in the old wells, of about 2 feet per annum, in the level to which the water rises; it now stands at from about 45 to 65 feet below high-water mark.‡

But not only is there a gradual annual fall in the water-level, but a temporary one is almost always produced by continued pumping; nor are the effects confined to the well where the draught is taking place, it extends for some distance around, and is, as has long been observed, apparent in all the adjacent wells. This sufficiently shows the limited capacity of the subterranean reservoir, and the small aggregate dimensions of the fissures, for considering the large

* I have here to express my obligations to Mr. R. Mylne for valuable information on many of these points.

† See a Paper by the Rev. Mr. Clutterbuck, "On the periodical alternations and progressive permanent depression of the Chalk water-level under London," in the 9th vol. of the Proc. Inst. Civ. Eng. for 1850, which, with the discussion that follows, contains much important information on this subject. According to Mr. Clutterbuck the depression caused by the abstraction of water at London extends as far north as Hendon or Edgeware, at the former place the water-level being now 6 feet lower than formerly; also that a sudden rise of the Colne affects the London wells.

‡ Proc. Inst. Civ. Eng. Vol. IX. p. 161, 1850, and letter to *Daily News*, March 14th, 1850.

mass of chalk saturated with $\frac{1}{3}^{rd}$ of its bulk of water, if it could deliver freely the water which it so rapidly absorbs, no draught that could ordinarily occur would, for a long period, produce a perceptible effect. In the Artesian well at the Mint, a day's pumping reduces the level of the water 20 feet, after which it remains stationary, delivering 240 gallons per minute.*

64. I do not think that any estimate of the quantity of water likely to circulate in the mass of the chalk, can be founded only on calculations of the extent of surface and the fall of rain. In the first place, a portion of the chalk being covered by retentive clay, much of the rain falling on it is lost by evaporation; and, in the second place, the surface, when bare, is so full of crevices, by which a very great extent of small surfaces of the rock are exposed, that a large quantity of the rain-water must be imbibed by the upper portion of the chalk itself, and which will be retained by capillary attraction near the surface, and remain subject to the influence of evaporation and vegetation. When the fall of rain is heavy, the surplus water will pass deeper into the mass of this formation, not by permeation properly speaking, but through fissures; and as there is no natural issue for the water below the Tertiary series, all the fissures below their margin tend to fill up, and consequently their boundary line forms a permanent water-level. It is therefore more especially in the zone of chalk, which immediately skirts the Tertiary district, that springs abound.† Where, in addition, the chalk is much

* Brande, Quart. Journ. Chem. Soc. Vol. II. p. 345, 1850.

† Amongst the many fine springs of the chalk district may be mentioned—that at Sittingbourne, which gave sufficient water to supply moving power to a paper-mill. In 1835 this spring, however, partially failed; but recourse was had to boring, and a plentiful supply of water obtained:—at the Bourne mill near Farnham; at Leatherhead, close to the Guildford road; at Croydon near the church; at Carshalton; at Orpington; the Holywell at Kempering, on the south side of the North Downs; at Birchington in the Isle of Thanet; Lydden Spout near Folkstone; the Holywell at the foot of Beachy Head cliff (Mitchell, Proc. Geol. Soc. Vol. III. p. 134); Bedhampton, near Portsmouth. These are but a few of a much larger number.

fissured, and receives a great extent of drainage, those portions of it forming the surface of some valleys, are gorged with water. The valley of the Colne at Watford is a remarkable instance of this. Many of the valleys near Gravesend exhibit to some extent the same phenomenon.*

It is owing to no deficiency in the supply of water at the surface of the chalk, but rather to the highly absorbent power of the rock, and to the restricted size† and extent of the channels (in proportion to the mass of the deposit) through which the water can pass, that in the chalk beneath the Tertiary strata the supply does not meet even the present demand;‡ and that the larger portion of the drainage of the extensive chalk tracts, is thrown off by springs in their low valley levels: for it will be observed, that although in a chalk country there is no drainage on the surface to form any streams, yet a number of small rivers have their rise in some of the valleys intersecting these tracts.

65. *Conditions of Springs in the Chalk.*—The annexed diagram (fig. 17) may serve to explain some of the above-mentioned points.

* Instanced by Mr. Barlow in his Report to the Directors of the South Eastern Railway.

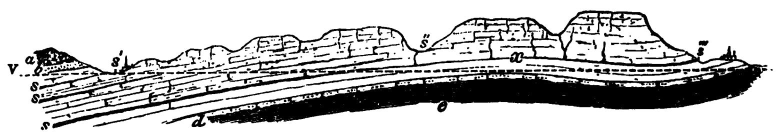
† Very different opinions have been expressed with regard to the size of the fissures in the chalk. I believe that large fissures very rarely exist in the deep-seated beds of chalk, or where it is covered by the Tertiary strata. In the first place the mass has not been sufficiently disrupted; and in the second place, the flow of water through it has been excessively slow. But in the hills of a chalk district, on which the shattering effects of disturbances have had freer play, and through which the passage of water has been far more rapid and constant, there I can readily conceive the existence of large open fissures, although even then they appear to be by no means common. Where they occur they do not materially facilitate the passage of water, for to transmit larger quantities it would be necessary that these fissures should be of the same size throughout, which they never are.

The almost only clear instance I have met with of a really large cavity in the chalk, occurred in sinking a well near the edge of the escarpment at Knockholt, in Kent, where at a depth of 270 feet the workmen came to a *cave*, 30 feet long, 12 broad, and 18 feet high, but of irregular shape, at the bottom of which ran a stream of water.

‡ It is possible that lower in the Chalk beneath London a larger supply of water might be found than is obtained at the present depths. This probably would occur on reaching the Chalk marl.

Fig. 17.

General view of the Chalk between the Tertiary and Gault districts on the north of London.



a. London Clay.
b. Lower Tertiary strata.
c. Chalk.
V L. Low valley-level.
d. Upper Greensand.
e. Gault.
s' s'' s'''. Springs at the surface.
s. Underground springs.

The vertical lines descending from these hills, indicate the position generally of the fissures conducting water from the surface; and the other lines, in which they terminate, those in the planes of stratification, along which the water afterwards passes. V L is the lowest valley-level of the district, below which the fissures (*s*, *s*, *s*), and all intermediate ones, tend to keep constantly full; and further, between *s'* and *s'''* the waters rise in these fissures above the level V, L, to a height varying according to certain conditions before alluded to (¶ 58). In Hertfordshire the Rev. Mr. Clutterbuck has shown that, commencing at *s'* and proceeding towards E, this rise in the water-level amounts to 13 feet per mile.* Most of these fissures communicate one with another, and the water overflowing from them will find its way out at the point of lowest level or vent *s'*, and also in any valleys between *s'* and *s'''*, of sufficient depth to touch the line of water-level just described. The line *s'''*, *x*, *s* marks the top of the chalk marl; this is always an important water-level, and it is doubtful whether the water penetrates any deeper.

The chalk is usually represented as dipping from its escarpment E, without variation, to its outcrop from beneath the

* This is not clearly shown in the diagram. The water-level may in fact be supposed to form a curve between *s' s'''*, attaining its culminating point at *x*. A greater elevation should also have been given to the whole mass of the chalk at *x* and E, and the valley at *s'''* be on a higher level.

Tertiaries at s', whereas it is probable that some form of variable curve, approaching to that shown above, is the more usual one. This will explain the cause of the many beautiful springs on the slopes and at the base of the chalk escarpment, for if the strata rise higher at x than they do at s''', the water passing through the chalk between these two points will tend to flow towards and escape as a perennial spring at s'''.

But if the strata rise higher at s''' than at x, then the depression between these two points will gradually fill, until the water ascends above x, when it will escape over that curve and descend the slope towards s; and if that portion of the water-channel which passes over the curve at x, has no communication with the surface, directly or indirectly, it will act as a syphon on the water accumulated between x and s''', which will then continue to flow so long as any remains in the shorter limb of the natural syphon; when this is accomplished the discharge of water will cease, and not recommence until after an interval sufficiently long to allow of the refilling of the reservoir between x and s'''. In the above figure the water thus transferred would be diffused through the fissures between x and s'; but if x were higher, or the valley at s'' deeper so as to intersect the line $x\ s$, then the discharge from this line of fissure would pass out at the surface of that valley, and form an intermittent spring, a phenomenon not uncommon in chalk districts, as the Bourne, near Croydon, the Lavant in Sussex, and others. Alterations in the curve and dip of the chalk will produce corresponding changes in the water level of the district, and in the flow of its springs.

In this diagram, as well as in that of fig. 18 (p. 94), referring to the greensand, the question is considered apart from any exceptional effects produced by faults and breaks in the strata. These disturbances frequently stop the underground flow of bodies of water, and throw them out at the surface

wherever the ground is lower than the outcrop of the stratum in which the water was flowing.* (See Appendix B.)

Unlike, therefore, arenaceous strata,—through which water permeates with facility in all directions, and where it tends to take the form of large sheets co-extensive with the strata themselves, — the percolation of water in the chalk occurs partly in the seams of bedding, and partly through fissures irregularly distributed, the direction and dimensions of which can be determined only by experience.

Since this section was written, Prof. Ansted has communicated to the Institution of Civil Engineers a Paper in which he gives an account of a series of experiments which he had performed in conjunction with Prof. Miller. They show that the absorbent power of dry chalk is such that a cubic foot of it imbibes about 2 gallons of water, or nearly one third of its bulk.

It is to be observed, however, that this is a character by no means peculiar to the chalk, since all earthy and sandy rocks can hold more or less water; but it does not follow that they are permeable in the ordinary sense of the word. Water passes through these formations, in the same way as through the chalk, viz., by fissures, and along the planes of stratification. We have some important information on the absorbent power of rocks in the experiments of Profs. Daniell and Wheatstone, given in tables connected with the "Report of Commissioners respecting the stone to be used in building the New Houses of Parliament," 1839. These tables show that out of thirty-six building stones, the bulk of water absorbed varies from $\frac{1}{86}$ to $\frac{1}{4}$, which is nearly equal to from $1\frac{1}{2}$ pint to rather more than $1\frac{1}{2}$ gallon per cubic foot.

Prof. Ansted, in his recently published "Elementary Treatise on Geology," enters into further detail on this question, and treats also of many other important points connected with the general subject of this inquiry.

As bearing also on this subject I would refer to the valuable Report of Mr. R. Stephenson, "On the Supply of Water to Liverpool, 1850," in which the conditions of the New Red Sandstone as a source of supply by means of Artesian wells, is discussed at length.

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* The large springs of Chadwell, near Ware, and others between Hertford and Hatfield, appear to me to be probably owing to the operation of an east and west *fault*, dislocating the strata, and stopping part of the water in its subterranean course from the hills north of Ware and Hertford. In the Chalk a very small fault would suffice for this object.

§ 6. *The Upper Greensand.*

66. Thus far we have had to treat of Formations, the water-bearing conditions of which are in great part practically known. No attempt has, however, been made in the neighbourhood of London to traverse the chalk, and to prove experimentally what sources of water-supply may exist beneath that deposit. Into this point I purpose now to inquire.*

The Chalk is immediately underlaid by a formation of very irregular development, and essentially arenaceous. In considering its capabilities as a water-bearing deposit, it will be convenient to proceed in the same way as we have done with the beds between the Chalk and the London Clay, adopting the like arrangement into four divisions. We shall thus be enabled more readily to institute a comparison between the probable productive power of these formations within the area centring at London.

67. From its small development and the almost total absence of sections, in the easterly parts of its range, the Upper Greensand formation has not attracted much attention as a water-bearing deposit. Nevertheless, when viewed over a larger and more westerly area, it presents a field deserving of investigation; for although so thin and insignificant, to the eastward of the meridian of London, it attains, as it ranges

* In the Greensand Formations I have taken as the basis of my plans and sections the valuable Paper of Dr. Fitton, " On some of the strata between the Chalk and the Oxford Oolite in the South-east of England" (Trans. Geol. Soc. 2nd Series, Vol. IV. p. 103), and the last edition of Mr. Greenough's Geological Map of England. The principal change I have ventured to make has been in the breadth of the outcrop of this Upper Greensand, which I have in some places materially reduced. I have also increased the superficial area of the Chalk Marl, and contracted that of the Gault. To the Lower Greensand I have in a few instances given a wider range.

westward, a not unimportant expansion, and exhibits also considerable uniformity of character.

In Wiltshire, Berkshire, Oxfordshire, and Surrey, it may be divided generally into two members,—an upper one consisting of loose or semi-indurated green sands, more or less argillaceous,—a lower one of soft green-sandstones, and of fine grained compact thin bedded and fissile calcareous sandstones, often very marly, of a very light green or whitish colour (at a short distance frequently even much resembling chalk in appearance), and overlying another but thinner bed of greenish sand, which passes into the gault. Its thickness varies from 40 to 50 feet in Surrey, to 140 feet, at least, in Wiltshire.

68. *North-Eastern Division.*—In this division of the map the Upper Greensand outcrops in a low tract of country ranging from the north-east corner of Norfolk southward through Cambridgeshire. But in a large part of its course it is so covered by beds of drift, that it would be extremely difficult to ascertain correctly its area. Dr. Fitton estimates its thickness to vary from 2 to 11 feet.

In the neighbourhood of Cambridge the Upper Greensand is said to be separated from the chalk marl above, and from the gault below, merely by the presence of a small quantity of dispersed grains of greensand in the thin junction beds between these formations.

The height of its outcropping edges, with reference to Trinity high-water at London, varies from a very few feet below to not many feet above that level; and its superficial dimensions bear but a very small proportion to the tract of country under which the deposit sinks, as it no doubt ranges co-extensively with the chalk (beneath which it dips at a slight angle), through the greater part of Norfolk and the whole of Suffolk and Essex. At two places within this area the chalk has been traversed and the Upper Greensand found

under it. In one case,* at Diss, the chalk proved to be 510 feet thick, and under it were 5 feet of sand, in which water was met with and rose to within 7 feet of the surface. The quantity is not stated. Secondly, at Mildenhall 250 feet of chalk and chalk marl were passed through, † then 11 feet of sand (upper greensand ?),—in which water was found,—and 9 feet of clay (upper part of the gault ?). In the deep well at Saffron Walden the upper greensand was not reached although 1001 feet of chalk were traversed.

From the position of the Upper Greensand in this division, from its being so much covered by drift, and its small development, it is probable that its water-value throughout this tract, is large.

A line of elevation crosses apparently from the borders of Bedfordshire to the coast of Suffolk, which, although rising gently and to no great height, may interpose a barrier to the subterranean flow of water, from the country to the north of it, to the London district.

69. *South-Eastern Division.*—The outcrop of the upper greensand in this division commences at Folkstone, and ranges along the foot of the North Downs to Godstone. At the former place it consists, according to Mr. Simms,‡ of a green sandstone, 15 feet thick, overlaid by 17 feet of beds passing into the chalk marl above; and at the latter place I found it to be from 40 to 50 feet.§ It dips beneath the chalk at an angle of from 5° to 20°.

* Transactions Geological Society, 2nd Ser. Vol. V. p. 137. Over the chalk were 100 feet of drift clay and sand.

† Ibid. 2nd Ser. Vol. IV. p. 311. In this case the chalk was not covered by any beds of drift.

‡ Proc. Geol. Soc. Vol. IV. p. 207.

§ It is not easy to assign an exact thickness to the upper greensand, as in the imperfect sections generally exposed it is difficult to determine where the chalk marl ends and the upper greensand begins. They appear, in fact, to pass one into the other.

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Division.—The outcrop of the upper division commences at Folkstone, and of the North Downs to Godstone. At onsists, according to Mr. Simms,‡ of a et thick, overlaid by 17 feet of beds marl above; and at the latter place 0 to 50 feet.§ It dips beneath the m 5° to 20°.

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1. In this case the chalk was not covered by any

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thickness to the upper greensand, as in the ca- is difficult to determine where the chalk marl n. They appear, in fact, to pass one into the

Its dimensions within this district are:—

Length of outcrop . . .	67	miles.
Superficial area	7	square miles.
Mean average thickness . .	25	feet.

The outcrop varies in height from about 200 feet above the sea at Copt-point on the coast, to about 450 feet at Godstone; but it is too narrow to receive directly any large share of rain-fall. Its position approaches to that shown at *b* in Fig. 11, being for the greater part on the slope of high and abrupt chalk hills, with this exception, that, being more compact and solid, it occasionally projects as a ledge of low hills at the base of the chalk escarpment. This feature, however, only begins to show itself, and that not very distinctly, in western Kent (see fig. 18, p. 94). It is a form of structure which enables those strata to receive, together with the water falling immediately upon them, a portion of that running off from the slopes of the chalk above; for, as these steep chalk hills present a large surface facing the south and south-west, a considerable quantity of water must be thrown off from them during the prevailing rains from those quarters of the compass.

The absence of drift on almost all this line of outcrop would favour the absorption of water on the surface; but from the small development of the upper greensand, and its argillaceous character, throughout this district,*—and the existence of several transverse lines of fault breaking the continuity of the strata,†—the difficulties presented to the subterranean

* In central Kent this deposit hardly seems to be a water-bearing stratum. According to Dr. Mitchell it is, at all events, apparently not recognised as such by the well-diggers, who state that they pass, in the wells at the base of the North Downs, through 50 to 150 feet of chalk and lower chalk, reposing upon blue clay (gault ?) 120 feet thick, and that upon sand (lower greensand ?) in which water is found.

† Dr. Fitton supposes the valley of the Medway to mark a line of fault, and Mr. Martin, in his Geological Memoir on part of western Sussex, ascribes to the same cause the origin of the lesser transverse valleys of the Cray and other small rivers. Mr. Hopkins draws the same inferences on theoretical grounds.

flow and accumulation of water in this division of the upper greensand must be considerable.

As this formation ranges into Surrey, however, its conditions of structure become more favourable.

70. *South-Western Division.*—In this division the Upper Greensand continues to range westward along the base of the North Downs from Godstone by Merstham to Farnham; from which point it trends to the south, owing to an extension of the chalk in that direction. It reappears for short distances in the small valleys of Kingsclere and of Shalbourne, and again emerges from below the chalk in the vale of Pewsey (see the Map). Thence it ranges by Devizes, and then turns northward, passing eastward of Calne in the direction of Swindon. Its thickness between Godstone and Reigate may be 50 to 60 feet, at Dorking it is apparently about 40 feet thick, near Guildford 50 feet, whilst at Farnham it measures from 84 to 90 feet. In the vale of Pewsey and at Devizes, it attains a thickness of not less than 140 feet. Turning eastward towards Swindon, its thickness begins to diminish.

The outcrop of the Upper Greensand at Merstham is 360 feet above Trinity high-water mark, falling gradually to 110 feet at Dorking, beyond which it ascends, but falls again to 100 feet at Guildford; it again rises at Farnham to 220 feet, at Burbage in the vale of Pewsey to 440 feet, and at Devizes to 400 feet, and thence declines slightly towards Swindon. Its dip varies considerably, being about 5° to 18° northward between Godstone and Dorking, 40° to 60° nearer to Guildford, and very slight around Devizes.

Its dimensions in this division are :—

Length of outcrop . . .	86	miles.
Superficial area	80	square miles.
Mean average thickness . .	76	feet.

From Godstone to Farnham the position of the upper greensand as a water-bearing stratum is far more favourable

than in the preceding south-eastern division. It not only crops out lower down the slope of the chalk hills, but more constantly projects as a small platform or ridge at their base. (See fig. 18, p. 94). It is in a tract extending for two to three miles on either side of Merstham that the upper greensand attains its greatest development along this line, forming a range of low hills at the foot of the Chalk Downs.* Beyond Betchworth it is not so well exhibited, but may be traced without difficulty by Dorking to Albury. Thence by Guildford to Farnham it is less conspicuous. At Farnham it again spreads out, occupying a wider and higher belt, and increasing in breadth as it ranges southward towards Alton and Selbourne.† In this latter district it is, however, much more argillaceous than at Merstham, and is known as the "Malm rock."

In Surrey generally soft light-coloured calcareous greensandstones,‡ and hard compact calcareous beds, interstratified with sandy marls, predominate. Below them is a bed of greensand, on reaching which water is usually found in abundance in all the wells sunk at the base of this part of the Chalk Downs. The upper beds are very argillaceous, and pass into the chalk marl.

In the vale of Pewsey and at Devizes the upper beds present thick masses of permeable loose and semi-indurated sands, more or less argillaceous, and very soft calcareous sandstones together probably 100 feet thick, underlaid by about 40 to 50 feet of fissile thin bedded calcareous sandstones, with a proportion of marls.

* Between Godstone and Merstham this is a very well marked and interesting feature. For three miles eastward of Merstham especially it has all the regularity of an artificial terrace, and forms a delightful walk. At Gatton, also, the Upper Greensand is well exhibited.

† See White's Natural History of Selbourne for a short account of the Upper Greensand and its waters, in this district.

‡ Often worked as a firestone.

The proportion of the rain-fall draining off from the lower marly beds of the chalk to this tract of the Upper Greensand must be large.

The Upper Greensand in this division is completely denuded, except where intersected by the transverse valleys of the Mole and the Wey, when it is covered by a drift of gravel.

These conditions of altitude of outcrop, increased thickness, greater permeability, and clean denudation, render it probable that a very considerable quantity of water passes into the Upper Greensand in this division, which may, if no important faults intervene, be transmitted from these gathering surfaces to the portion of this deposit which lies beneath London.*

71. *North-Western Division.*—In the western part of this division, likewise, all the conditions are most favourable for the accumulation of large quantities of water in the Upper Greensand. The area occupied by its outcrop is considerable, and it is generally free from accumulations of drift, the strata are for the most part arenaceous, and of considerable thickness. It ranges from the westward of Swindon nearly to Princes Risborough, and thence to within a few miles of Cambridge, forming a zone of very variable breadth at the base of the chalk hills.

Length of outcrop	102	miles.
Superficial area . . .	82	square miles.
Mean average thickness . . .	75	feet.

The elevation of this line of outcrop above the level of the Thames at London, varies—from about 400 feet near Swindon, 140 feet at Wallingford, 320 feet on north of Tring, to 135 feet on the north of Hitchin. The mineral character

* As all the main disturbances seem to run east and west, and not north and south, there is less probability that the continuity of the strata in their east and west range (from Wiltshire to London) is interrupted.

differs at first but little from that described in the previous section. But in proceeding eastward the lower fissile beds become much more argillaceous, and on the hills between Tetsworth and Cuxham, where this deposit is 70 to 80 feet thick, it assumes more the characters of the Malm Rock of western Surrey. At the same time the upper sandy division gradually decreases in thickness but exhibits a persistent bed of a pure dark green sand. Further eastward the whole mass becomes much thinner, and assumes a more argillaceous condition, until in Hertfordshire it can in some places hardly be distinguished from the chalk marl or the gault.* In Wiltshire it usually forms a high but narrow platform, or a narrow ridge of hills advancing beyond the chalk escarpment; but sometimes its slope is continuous with, and not to be distinguished from, that of the chalk. It attains its greatest breadth in Berkshire and Oxfordshire, between the hill of the White Horse and thence by Wantage and Wallingford, to near Tetsworth, forming a range of low hills, with a nearly bare surface throughout. In Buckinghamshire and Bedfordshire it contracts again into a narrow zone, but may be distinguished at intervals, as at Henton near Princes Risborough, and at the foot of the Sundon downs near Toddington, as a low and unimportant ridge at the base of the high chalk hills. In Hertfordshire and Cambridgeshire it seems to merge into the broad valley of the gault; but no sections are to be seen.

* Its most marked feature in this district is the upper stratum of dark, almost black, green sand. It is only by assuming this to be the bed mentioned as black grit, in the following section of the second well near Tring by Mr. W. Gravatt, that I can place in geological order the succession of strata he describes. (Trans. Civ. Eng. 1836, Vol. I. p. 151).

	FEET.		FEET.
1. Chalk . . .	30	4. Blue clay . .	82
2. Hard blue clay . .	34	5. Black grit . .	10
3. Blue stone . . .	4	6. Blue clay . .	108

It is probable that strata 2, 3, and 4, may belong to the chalk marl. No. 5 may be the upper greensand, and 6 the gault.

The dip of the strata along this line of outcrop is regular and at a moderate and small angle. I am not aware of any disturbance that would interfere materially with the subterranean flow of water from the surface of the Upper Greensand, in Berkshire, Oxfordshire, Buckinghamshire, and Bedfordshire, to London.

The Upper Greensand may be best seen at the firestone pits, one mile north of Godstone,—in the quarries at the foot of the Chalk Downs, one mile and a half due north of Bletchingly,—the pits at Merstham and Gatton,—the quarries one mile north-east of Reigate Church; and one furlong north-east of the Betchworth station,—the cutting on the railway three furlongs north of the Merstham station; and the one immediately east of the Dorking station; the hills between Farnham Castle and Ridgeway; the road from Devizes to Pottern,—the road from East Challow to Wantage,—and the hill crossed by Knightsbridge Lane, two miles north by east of Watlington. These distances are taken from the Ordnance Map.

§ 7. *The Gault.*

72. Immediately beneath the Upper Greensand, in every part of its course above described, is this deposit of bluish or dark greenish grey tenacious clay. Throughout its range it maintains an almost constant uniformity of lithological character, and does not vary materially in its thickness. It is 126 feet thick at Folkstone, 120 to 140 feet at Merstham, thinner apparently nearer Guildford,* about 100 feet at Devizes and Swindon, and increases again to about 150 or 160 feet as it ranges into Cambridgeshire. This formation is quite impermeable, and therefore holds up the water collected in the overlying strata of the Upper Greensand.

It naturally follows that as this mass of clay keeps up the water of the beds above, it should also keep down the water in any permeable beds that may be placed below it; and this must be the case with regard to the Lower Greensand, which immediately succeeds it in a descending order.

* At places between Merstham and Guildford it is said to be not more than thirty to forty feet thick, but no distinct measurement has hitherto been practicable.

§ 8. *The Lower Greensand.**

73. The range of this formation is about equal with that of the two preceding groups; but, unlike the Upper Greensand, which exhibits its minimum thickness eastward in Kent and Cambridgeshire, and attains its maximum thickness westward in Wiltshire,—and differing from the gault, which retains a thickness comparatively uniform over the whole area,—the Lower Greensand is very thin in North Wiltshire, and expands rapidly as it trends eastward into Surrey and Kent. At Devizes and Calne it does not exceed a thickness of from 20 to 30 feet; in Surrey it may average 600 feet,† while according to actual measurement by Mr. Simms,‡ it is 406 feet thick at Folkstone.

In Oxfordshire this formation is again thicker than in Wiltshire. In Buckinghamshire Dr. Fitton's sections would indicate a thickness of probably from 150 to 250 feet. In Bed-

* This name must not be taken as an indication of its general aspect or mineral character. It is merely the geological designation. In the *Upper Greensand* the general tone of colouring and the lithological character are somewhat in accordance with the name. But with regard to the *Lower Greensand* around London, the prevailing and almost universal colours are yellow and ochreous, from the lightest tints to the darkest ferruginous shades. Green sands and dark clays are comparatively rare. So far back as 1824 Dr. Fitton (Annals of Philosophy) noticed the inconvenience of this nomenclature, both on the ground mentioned above, and on others purely geological. In 1845 (Journ. Geol. Soc. Vol. I. p. 189), he again observed upon "the objections to which the name of *Lower Greensand* is exposed," and suggested that "a new denomination should be taken from the *Isle of Wight*, where the sections on the coast are remarkable for their distinctness." I could have wished to have used another name, and hope that some alteration, as suggested by Dr. Fitton, may yet be made.

† In his Geology of Western Sussex, Sir R. Murchison shows that at Petworth the Lower Greensand had been found to be not less than 400 feet thick.—Geol. Trans. 2nd Ser. Vol. II.

‡ Proc. Geol. Soc. Vol. IV. p. 207.

fordshire I judge it to be about 300 thick; thence through Cambridgeshire it decreases in thickness, and is, in Norfolk, according to Mr. Rose, about 80 feet thick.*

74. The Lower Greensand is composed of a variable series of strata. In Kent, Dr. Fitton states that it is separable into three natural divisions;—an upper one of white, yellow, and ferruginous sands,—a middle division of clayey and ferruginous green sands, and clays,—and a lower one of calcareous stone (Kentish rag) and sands passing down into clays.

This triple division is not so well defined in Surrey, where many of the clay beds, as well as the coarse limestones, are almost entirely replaced by sands; and in Wiltshire and Oxfordshire these divisions are not apparent. Indications of them are scarcely perceptible in Bedfordshire, the formation there consisting chiefly of loose incoherent sands and soft ferruginous sand-rocks.

75. The Lower Greensand in Kent and Surrey forms a zone, ranging parallel with the escarpment of the North Downs. It rises gradually, in general, southward from the valley of the gault, and ends in a somewhat abrupt escarpment 400 to 600 feet high, overlooking the lower district of the Weald (see fig. 18, p. 94).† The general characters of this formation are easily noticed in the country between Seven Oaks, Reigate, Dorking, and Godalming, all of which towns are situated upon it. In this district it consists of thick masses of coarse quartzose, light yellow sands, interstratified with others of a finer grain, and of brighter colour, ochreous and shaded red, and sometimes nearly white.

Thin and irregular bands of hard very ferruginous sand-

* Phil. Magazine, 1823, Vol. LXI. p. 81—83.

† Leith Hill, which is, according to the Ordnance Survey, 993 feet above the level of the sea, forms part of this line of outcrop. Box Hill, on the contrary, forms part of the escarpment of the chalk.

stone, and seams of cherts, are common in some of the sands. Subordinate to the whole are a few beds of green sands and clays, and at Nutfield a bed of fullers' earth. In some places the strata pass into soft porous sandstones, and in others they again become argillaceous;—a few are calcareous (Bargate stone). As a whole the Lower Greensand in these districts is very absorbent and permeable, and often forms extensive dry sandy heaths.

In Bedfordshire and the adjoining parts of Buckinghamshire and Cambridgeshire, this deposit forms a tract of a less bold character than in Kent and Surrey, but still sufficiently prominent and distinct; and here also it is more purely arenaceous and uniform than southward of London,—consisting of a mass of light yellow and ferruginous sands, with thin seams of iron-sandstone. The upper part of it frequently passes, as around Silsoe especially, into a thick bedded rock of soft coarse ferruginous sandstone. The sands of Woburn and Ampthill are well known.

76. The range of its outcrop is parallel with that of the Upper Greensand, the contour of which it follows, separated merely by the lower tract of the gault.* Its breadth is considerable; in Kent and Surrey varying generally from two to five miles, and in Buckinghamshire and Bedfordshire from three to four miles.

As this deposit is so much thicker and more variable and less defined in its structure than the Upper Greensand or the Tertiaries, its details are not so well known; as the description must consequently be more general, it may be convenient to consider the different divisions of the Map together.

The surfaces of the Lower Greensand in these several divisions exhibit the following important dimensions:—

* Except in part of Berkshire and Wiltshire, where its outcrop is disturbed by faults, and is altogether wanting for a distance of many miles.

		Square miles.
South-eastern division, extent of superficial area	.	215
South-western „ „ „	. .	135
North-western „ „ „	.	260
North-eastern „ uncertain, about	.	40
		650

77. As with the Upper Greensand, the outcrop of this formation is usually bare and denuded, a thin layer of earth alone protecting the abraded edges of the arenaceous strata. In Kent and Surrey its surface is, with very few exceptions, without any covering of drift: the case is the same, but to a lesser extent, in Wiltshire and Oxfordshire. In Buckinghamshire and Bedfordshire it is often covered by thick beds of gravel, which is, however, for the most part sandy and permeable; but in the latter county the gravel is again overlaid in many places by the impermeable "boulder clay" drift. In Cambridgeshire and Norfolk the covering of drift is more general and impermeable.

The thickness of the lower greensand in the district under review has only been determined accurately at Folkstone.* At the other places the thickness is merely a rough estimate founded upon general observation.

		FEET.
Kent	Folkstone	406
	Seven Oaks . . .	500
Surrey‡ . . .	Chilworth, between Dorking and Guildford	680†
	Farnham	700
Wiltshire . .	Devizes and Calne . .	20
Oxfordshire . .	*Generally*	150
Buckinghamshire	Leighton Buzzard . .	250
Bedfordshire .	Woburn	350
	Biggleswade . . .	250
	Average thickness .	367

* In the Isle of Wight, the fine coast section of the Lower Greensand has been carefully examined, both by Dr. Fitton and Captain Ibbetson; the former by line found the thickness of this deposit to be 805 feet, and the latter, by trigonometrical survey, 833 feet (Journal Geol. Soc. Vol. I. p. 190, and Vol. III. p. 330.)

† This is a tolerably exact general measurement recently made with Mr. Austen.

‡ Mr. Middleton, who appears to have been a careful observer, differs somewhat from

78. At Folkstone about 150 feet out of the 406 consist of clay, and the remainder of sands and ragstone; at this point, therefore, we may take $\frac{3}{5}$ths of the deposit to consist of permeable strata. But in proceeding westward the clays gradually diminish, and are replaced by sands, so that in the thickness of 680 feet at Chilworth we found a central group of mixed clays and sands, measuring only about 130 feet, or less than $\frac{1}{5}$th of the mass. In Wiltshire the deposit consists of sands only, and apparently so in Oxfordshire. From Leighton Buzzard to Woburn and Biggleswade, a tract in which the Lower Greensand is largely developed, there are very few beds of clay interstratified with its sands. Taking, therefore, all these districts together, if we exclude rather less than a third of the mass as consisting of clays, it will probably more than meet the necessities of the case; and we may consider this group as consisting of 117 feet of impermeable clays, and of 250 feet of permeable sands. The mineral character of this series is so variable, that it is possible that even these middle clays, although so important in Kent, may not be spread over the whole underground area, and that there may be at some central point a communication between the different main masses of sand of the upper and lower divisions.*

me in his estimate of the thickness of this and the other deposits in Surrey. He assigns to them the following dimensions:—("Manning and Bray's History of Surrey," Vol. III.)

	FEET.
Clay and sand (Tertiary series) about	300
Chalk	800
Blue marl (gault)	30
Fuller's earth and sand (Lower greensand)	413
Weald measures	457

* The Upper Cretaceous deposits have been penetrated, and the Lower Greensand reached, at the following places,—

A well near Wrotham in Kent, at the base of the North Downs, mentioned by Dr. Mitchell, the section of which gave—

Upper and lower chalk	140 feet.
Blue clay (gault ?)	126 „

(see over)

79. The height of the outcropping surface of the Lower Greensand above the level of London is, on the whole, very considerable. Commencing in the valley of Dart at Riverhill and Westerham, we there find the bottom of the valleys to be 210 to 260 feet, at Godstone about 450 feet, at Reigate from 250 to 280 feet, and thence to Farnham on an average 200 feet, above Trinity high-water mark,—excepting at Dorking and Guildford, where the Mole and the Wey cut through this formation and reduce the height of the surface to about 100 feet. North of London the surface of the Lower Greensand is 270 feet high at Leighton Buzzard, rises to about 300 to 350 feet in the neighbourhood of Woburn, thence gradually descends to 120 or 130 feet at Biggleswade, and to a still less height in Cambridgeshire, above the level of the Thames at London. These however are but the lowest points. In Kent and Surrey the Lower Greensand hills rise 200 to 600 feet above these levels, and in Buckinghamshire and Bedfordshire, 200 and 300 feet.

The surface of the Lower Greensand is so placed that it cannot, except in a few rare cases, receive any additional supply of water by drainage from adjacent districts; but from its permeability, its extent, and elevation above the

Below this came sand; and water rose to within 130 feet of the surface.

At Snodland on the Medway the water in a well (like that near Wrotham) rose over the surface.

At Gatton Park a well was sunk through 380 feet of firestone and gault; then 20 to 30 of red clay and pebbles. The water rose to within about 290 feet from the surface (the ground here is probably 400 to 450 feet high).

Dr. Fitton mentions a well at the Feathers Inn, Merstham, sunk 150 feet through gault to the underlying Lower Greensand, whence a plentiful supply of water was obtained. (Trans. Geol. Soc. 2nd Ser. Vol. IV. p. 140.)

The Rev. J. C. Clutterbuck informs me of a well a few miles north of Baldock where the Lower Greensand was reached under a depth of 170 feet of gault. The water rose (1834) to within 3 feet of the surface, and has maintained that level ever since.

At Cambridge, Artesian wells are very numerous. They traverse the gault (130 to 140 feet thick?); and immediately on reaching the Lower Greensand, water is found, which rises to within a few feet of the surface of the ground.

level of the Thames, it is peculiarly well adapted to receive and transmit the rain-water falling within its own area.

80. With regard to the passage of water from these beds at their outcrop to any point beneath the chalk, there is some uncertainty how far it may be interfered with by faults and disturbances; for in Surrey and part of Kent,* on a line parallel with the North Downs, and at a short distance from them, some very considerable faults, or rather flexures, run through the Lower Greensand, bringing at some places in their course, the lower beds of this formation, and occasionally the Wealden, to the surface of the ground in the midst of the Greensand area. If this could be attributed to one continuous line of disturbance ranging in equal force and uninterruptedly, it would certainly exclude much of the broad zone of exposed surface of the lower greensand from contributing to the supply of water in its deeper-seated beds below the chalk; but this I do not apprehend to be the case. Lines of disturbances are of very variable intensity, and, although interrupting occasionally the continuity of the strata, their effects, at some intermediate places, may be much less important; so that although the water may be kept back by faults in some parts of the greensand area, yet the communication is probably kept up in other parts where the disturbance has not been so great.

The tilting up of the chalk in the singular ridge of the Hog's-back, and the rise of the Wealden one mile to the south of Guildford, are no doubt owing to one and the same disturbance, which, if prolonged eastward, most probably passes to the south both of Dorking† and Reigate, and is possibly

* For a description of some of these disturbances see Dr. Fitton's paper, before quoted, pages 132-6, and Dr. Mantell's "Geology of the South-east of England."

† Since the pages above were written Mr. A. K. Barclay has shown me that the tract of the Lower Greensand to the south-west of Dorking is distinctly separated into two areas by a broad tract of clay, which by its organic remains proves to belong to the Wealden formation. This is particularly apparent in the valley immediately

the same which fractures at Tilburstow Hill near Godstone, and then ranges at or near the outskirt of the Lower Greensand, in the direction generally of Maidstone. If this be its course, this disturbance, which is the most important one in the district, would pass outside, and not affect the area of the Lower Greensand between Dorking, Reigate, Godstone, and Westerham,—the zone of greatest consequence for the supply of water to this deposit beneath London. There are, however, several lesser lines of disturbance traversing this district, but they are of minor importance. From Farnham to Guildford, and Albury, the Greensands are tilted up at a high angle of 40° to 60°; but to the eastward of the latter place the angle is always much less, rarely exceeding 20°, and more generally falling to 5° or 10°.

81. Passing to the northern outcrop of the Lower Greensand, we there find its continuity distinctly broken for a considerable distance in its range through Berkshire, and cut off from contributing in any degree to the supply of water in the central districts. This is owing, probably, to a great fault, extending, in the valley parallel to the chalk escarpment, from the west-south-west of Swindon to near Abingdon: the disturbance being of such a magnitude as to remove the lower greensand, bringing up the Kimmeridge clay to the place which it should occupy on the surface.

In its range from this point to Cambridgeshire, this deposit may be traversed by other lines of disturbance, but

south of Bury Hill. This line of disturbance is laid down on the Map, but I was not at all aware of the extent of the elevation, until its importance was pointed out to me by Mr. Barclay. Therefore this promontory of the Weald is not shown; it is such that it excludes a great part, and would exclude the whole, of the Leith Hill district from forming part of the effective area, if this axis of disturbance, which Mr. Austen had before ascertained to be extremely conspicuous at Chilworth, should prove to be continuous in its effects between Dorking and Guildford. But this is doubtful.

I find however that Mr. Hopkins, in his Paper on the Theory of the Wealden, in describing the range of this line of disturbance, has been the first to notice the occurrence of the Wealden at Bury Hill (Geol. Trans. Vol. VII. p. 19, 1845).

I do not think that the continuity of the strata is sufficiently broken to keep back the waters received at its outcrop.*

If the Lower Greensand were a thin group of strata, a small fault might cause a complete break; but in a deposit several hundred feet thick, and composed in greater part of thick beds of sand irregularly recurring, unless the extent of vertical disturbance should everywhere exceed the thickness of the formation, a certain amount of communication would be kept up between the opposite sides of the fault whenever the disjointed edges of any of the numerous beds of sand came into juxtaposition, especially where the depth of the strata caused the pressure of the water to be great.

The reader, who has passed over the physical details commencing at p. 19, may here resume the more general description.

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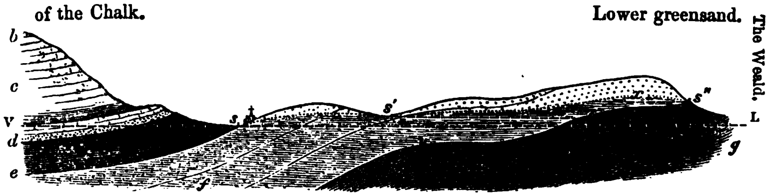
82. *On the Springs in the Lower Greensand.*—An attempt has been made to illustrate by a diagram the distribution of the free water in the mass of the chalk (p. 72). The object of fig. 18 is to exhibit the same phenomenon in the Lower Greensand, and to show the position which this formation holds relatively to the Upper Greensand, the Gault, and the Wealden. This transverse section is intended also to embrace the leading physical features of the greensand district on the south of London, and to give a general representation of the country between the North Downs, and the weald of Kent and Surrey, a distance of from three to six miles.

The greater part of this tract is occupied by the Lower

* I suspect that there is a considerable disturbance in this formation in the neighbourhood of Aylesbury. It may be a prolongation of the disturbance noticed near Swindon, and deserves attention, as affecting in some measure the present question.

Greensand, whose breadth varies according to the curvature of the strata,—being narrow when the curve takes a rapid bend upwards, and wider where it is prolonged, or forms a series of rolls.

Fig. 18.



b. Lower Tertiary strata.
c. The chalk.
d. The Upper Greensand.
e. The gault.
f. The Lower Greensand.
g. The upper part of the Wealden Formation.
V L. Line of lowest valley level of the district.
s, *s'*, *x*, *s''*. Line of water-level.
s, *s'*, *s''*. Springs.

The edges of this formation are bounded on the north by the Gault at *s*, and on the south by the Wealden at *s''* ; they are both impermeable strata, and present water-tight surfaces to the sand between them, so that any water which might find its way below the margins of these deposits could not escape again, but would follow the subterranean course of the intermediate strata. In the process of time, and by the constant operation of the rain-fall, the large underground mass of the Lower Greensand has been filled to its edges with water, and any further addition causes it to run over. It is this overflowing which gives rise to the springs of the district. Their magnitude will depend upon the breadth and "massif" of the Lower Greensand, and upon the difference of level of the Gault and Wealden.

83. We will now assume that the Lower Greensand consists throughout of sands of uniform texture. Supposing that no rain had fallen for such a time that the waters con-

tained in it were in a state of equilibrium: they would then stand at the level V, L, and all the springs would cease to flow. But when the mass of strata above V L is large this can rarely happen, on account of the fall of rain taking place from time to time throughout the year, and the texture of the strata opposing a certain resistance to its passage, which impediment to its transit is sufficient to diffuse, uniformly over a long period, the delivery of the water that it receives irregularly at shorter intervals.

The water first percolates downwards through the sands until it reaches the line of water-level, and then flows horizontally towards, and tends to escape at, the point of lowest surface-level *s*. (We are now supposing that this is the only vent.) The successive rain-falls keep adding to its volume, until the resistance presented by the lithological structure of the mass is balanced by the weight of the head of water accumulated above the level *s*, L; the flow at *s* then becomes constant, and the mean daily delivery will be an average of the total quantity of rain infiltered during a month, a year, or even a longer period, according to the size of the mass in which the water is stored.

Where, however, there are more than one point of issue, if the marginal edges of the two series of impermeable strata at *s* and *s″* are on the same level, the water flows both ways in nearly equal force; but when, as in fig. 18, the Wealden at *s″* rise above the Gault at *s*, the water tends to accumulate in the Lower Greensand *f*, until it reaches a line connecting *s* and *s″*. This line will not be straight, but will present a curve varying constantly in its form according to the distance between *s* and *s″*, the resistance opposed to the passage of the water, and the variation in the rain-fall. This would not so much affect the main spring at *s* as the minor ones at *s′* and *s″*, for when the curve *s*, *s′*, *x*, *s″* reaches, at *x*, a level higher than the point *s″* the water above the line pro-

longed horizontally from *s''* will tend to find its level and escape at *s''*, notwithstanding the rise of the strata in that direction. This spring would be the first to cease to flow in dry weather. A further fall of the water-level to the line *s' z*, would next affect the spring at *s'*, whilst that at *s* might, still maintain its perennial character, so long as any water sufficient to overcome the resistance of the strata remained above the level of V, L.

84. The sands being of comparatively uniform texture and resisting power, water can pass through them freely in all directions; and that which is stored in this Lower Greensand will tend rather to overflow, not at any particular points only, but along the whole length of the rim of the Gault,—to ooze out in fact along the entire line of the valleys at *s* and *s'*, the transverse section of which is shown in fig. 18, except where a local depression in the lip of the Gault diverts a greater flow and issue of water than usual to that point. In consequence of this lithological character the springs in arenaceous strata are generally not so large as in the chalk or similar deposits, where the water is confined to and issues through a few large channels.

85. Some conception may be formed of the permanence which these springs may exhibit when it is considered that the fall of the water-level, *s*, *s'*, *x*, *s''*, of one foot over an area of one square mile, probably sets free not less than 50,000,000 gallons of water. But the water having to move laterally, and entirely through small channels (the interstices of the sands), and not having the advantage of the pressure which is exerted at greater depths, its motion is slow; and as it overflows the marginal edges of the strata generally,—and also transudes and escapes at the surface wherever subordinate beds of clay occur,—a large quantity, not being in bulk sufficient to form permanent springs, must be lost by evaporation. It is where the transverse depressions in the zone of outcrop are

lowest, that the springs from these sands are likely to be the strongest and most numerous.*

When the Lower Greensand contains subordinate beds of clay, the line s, s', x, s'', will necessarily be interrupted, and the spring system of the district will become more complicated; but the same rules will still apply to each separate group of strata.

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86. The following are a few of the places where sections showing the structure of the Lower Greensand may be seen :—

Upper Division.

The sides of the lane commencing at the London Road, three furlongs northward from Limpsfield Church (Kent), and running through Laurel Grove to Limpsfield Common. Pits near Betchworth (Surrey),—one, five furlongs on the Dorking Road,—another, one furlong on the Reigate Road. Sides of the lane leading from the Punchbowl Inn (three-quarters of a mile from Dorking, on the Reigate Road), southward to Chart Park. Sides of the lane leading from Tittings Farm near Chilworth (Surrey), southward to Halfpenny Farm. (This section shows both the upper and lower divisions—it is an almost perfect and very interesting section of the whole series of strata composing this formation). Pits immediately east of Silsoe, Beds.

Lower Division.

Pits on the common immediately south of Limpsfield. Cutting at the junction of the Brighton and Dover Railways. Road cutting over Tilburstow Hill, immediately south of Godstone, and the pits on the east of the road at the top of the same hill. Pits at Cold-harbour on the top of Leith Hill. Road cuttings on the high road from Woburn to Newport Pagnel,—the first two miles out of Woburn.

General Sections.

Railway section from the Leighton Buzzard station (Bucks) northward for two miles beyond it. Railway section from Biggleswade (Beds) northward to Sandy. Part of the cuttings on the railway between Reigate and Guildford (the other cuttings on this line are through the Upper Greensand and the Gault). Railway sections adjoining Farnham.

Beside these particular localities, good sections are exhibited very commonly on the sides of the lanes and roads throughout a large portion of these districts.

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* As in and adjoining the valley of the Mole where it enters the Greensand at Dorking, that of the Wey south of Guildford, and of the Dart at Riverhead.

§ 9. *The Weald Clay and the Kimmeridge Clay.*

87. The Lower Greensand is, throughout, incumbent upon one or other of these formations; which, as they consist of impervious strata of clay usually several hundred feet thick, effectually prevent the downward escape of the water, accumulated in the overlying beds.

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88. The following table shows at one view the extent in square miles of the superficial areas of the several formations described in the foregoing pages, with reference both to the divisional arrangement that has been adopted and to the entire surface occupied by each deposit within the boundary of the map.

Geological Formations.	Divisional Areas.				Total Areas. Square miles.
	South-eastern.	North-eastern.	South-western.	North-western.	
a. London Clay........	130	1460	696	295	2581
b. Lower Tertiary Strata..	195	64	45	50	354
c. Chalk..............	584	1430	730	1050	3794
d. Upper Greensand	7	3	80	82	172
e. Gault..............	38	94	28	180	340
f. Lower Greensand	215	40	135	260	650
	1169	3091	1714	1917	7891

These, however, are to be considered only as approximate measurements.

IV.—GENERAL INFERENCES.

§ 10. *On the Relation between the actual and the effective superficial Areas of the several Water-bearing Deposits.*

89. It has been convenient in the preceding pages to divide the whole of the area, occupied by the Lower Tertiary and Lower Cretaceous strata on the Map, into four divisions, and to consider each group separately in stratigraphical order. It cannot fail to have been observed that the position of outcrop, and the lithological character of the several formations, are liable to such variation, that the proportion of the rainfall that can pass into the strata becomes materially modified, and depends upon other conditions than those of superficial area solely. We will now endeavour to attach some definite value to these interferences, and to eliminate the portions of the surface which may represent the really effective areas; although these must be viewed only as very general approximations made merely to meet, in some measure, the necessities of the case, and to indicate the course which should be taken. Having, however, thus obtained a series of numerical results connected with the dimensions of the different strata, we can endeavour to determine their relative importance as sources of water-supply. It will be desirable also to ascertain whether these strata receive any portion of the water gathered on the adjacent impermeable deposits.

90. It has been shown that in the districts east of the meridian of Deptford,—including north Kent, Essex, Suffolk, Cambridgeshire, and part of Herts,—neither the Lower Tertiary strata, nor the Upper Greensand appear to contribute, except

in a very small degree, to the supply in the metropolitan district (¶ 32, 40, 45, 68).* This is important, for of the total area of the first of these formations, viz. 354 square miles, nearly 259 are, in consequence, at once excluded from our calculations; while only about 10 out of the 173 square miles of the second are lost. Our attention may, therefore, be confined to the portions of those formations situated west of that line, and whose relative superficial areas are:—

Lower Tertiary Strata . . .	95	square miles.
Upper Greensand . . .	162	"
Lower Greensand	395	"

From this list it appears that in the district east of the meridian of Deptford the exposed surface of the Upper Greensand is two-fifths, and that of the Lower Greensand more than four times, larger than that of the Lower Tertiary strata. But although these numbers give the dimensions of the areas of the water-bearing strata, they do not represent their exact and relative values, to which we must endeavour to approximate. All the detail bearing upon this part of the subject has been given in the preceding pages. We have now only to recapitulate the general results.

91. *Tertiary Strata.*—On the south side of this portion of the Tertiary district these strata form a narrow zone of outcrop from Croydon to Hungerford, and on the north, a broader zone from Hungerford to Ware. But it has been shown (¶ 23, 28, 46, 48), that, owing to the large development of the mottled clays in this group,—at points not more distant on the one side of this district than Leatherhead, or, at all events, Guildford, and, on the other side, than Maidenhead,—these Lower Tertiary strata frequently become almost impermeable; so that their outcrop, beyond a line connecting those places, is probably almost inoperative, in the supply of water to the beds beneath London. This would exclude,

* The case is different with respect to the Lower Greensand (¶ 93).

as ineffective, the whole of the superficial area westward of that line, amounting to twenty-nine square miles; or we will take twenty-eight square miles, as it is just possible that some small permeable beds may keep up a partial communication between these different portions of the Tertiary area. There remain eighteen miles of southern outcrop, the larger portion of which is probably effective; still, as the mottled clays occupy part of the zone between Guildford and Ewell, as a covering of drift is not uncommon, and as near Deptford the strata are a good deal broken by faults, I would further reduce the eighteen square miles to twelve.

Of the northern outcrop, we might take two square miles from Bray to Slough, and about three in the valley of the Lea in the neighbourhood of Hoddesdon and Broxbourne,—of Bow and Stratford; but even these portions of it are so much covered by drift that these five miles may be reduced to three of effective area. In all the intermediate tract the outcrop is so unfavourably placed, the mottled clays are so largely developed, and the surface is so generally covered by a drift of gravel, clay, and brick earth, that considerable allowances must be made for these causes. The value to be attached to them is of course in a great measure conjectural, but I am satisfied that the deduction on their account ought to be very large,—that of this portion of the outcrop we cannot take more than seven square miles as a contributing surface to the London district. The full extent of this north-western area is fifty square miles, which would thus be reduced to ten. This area may appear small, but it will, I think, be found sufficient, when we consider the supply of water in the south-western division, the effective area of which does not much exceed this size.

I would also take as a possible source of supply two square miles of the Essex or north-eastern division.

92. *Upper Greensand.*—From the more uniform lithological

character of the Upper Greensand, and the absence of drift on its surface, fewer deductions are necessary. The principal impediment to the infiltration of water arises from the partially argillaceous character of some of the strata.

From Godstone to Farnham the conditions of this deposit are, on the whole, extremely favourable for the reception of the rain-water falling upon it, as it usually presents a bare and absorbent surface, and forms a well-marked ridge of some breadth. The upper beds are argillaceous, but the water thrown off by them, usually passes on to the lower fissile and sandy beds, and is absorbed by them. From Farnham to Alton, however, the whole mass becomes, with few exceptions, so argillaceous, that the larger portion of that area must be reckoned as of no value. Between Godstone and Alton the Upper Greensand occupies an area of about fifteen square miles, and if we allow for unfavourable conditions, it may leave eight square miles of effective surface.

We then pass into the isolated greensand valleys of Kingsclere and Shalbourn;—these being what are termed "Valleys of elevation,"* the beds dip, from a line passing longitudinally through the centre of the valley, towards the sides, and therefore the flow of water in the strata will be determined in two directions—southward, beneath the chalk of Salisbury Plains, and northward, under the Tertiary series. This latter part of the area alone affects the supply in the London district; so that the other half (about one square mile) of the area in each of these valleys above-mentioned must be excluded as non-contributing surfaces.

So also in the vale of Pewsey, where the Upper Greensand attains its greatest development both in breadth and depth, one side only (about 23 square miles) of the valley has to be taken into account. On the score of subordinate

* For description of these valleys, see a paper by Dr. Buckland in Trans. Geol. Soc. 2nd. Ser. Vol. II. p. 119.

impervious strata, fewer deductions have to be made here, and through the remainder of the south-west division to its termination near Swindon; fifteen square miles out of the thirty-eight will probably more than suffice.

From Wiltshire to Buckinghamshire the zone of outcrop is usually broad, and placed, with regard to dip of the strata, position, and extent of surface, under favourable conditions as a gathering ground. It generally forms a range of low hills running parallel with the chalk ridges, the upper sandy beds cropping out in the small intermediate valley, and receiving much of the superficial drainage from the lower chalk hills. This structure is well marked at Wantage, and also between Watlington and Tetsworth, and continues as far as the Lower Icknield way, near Princes Risborough; but it is less perceptible as the strata extend eastward. This arises from the beds becoming gradually more and more argillaceous, the harder beds softer, and the whole mass thinner, until we arrive at the last-mentioned place, beyond which this deposit can be traced with difficulty.* As part of the Upper Greensand, in a large portion of this district, is argillaceous and impermeable, although only occasionally covered by a drift of gravel, it may be necessary to exclude forty square miles of this area, and to consider only thirty-four as effective.

From Risborough to Cambridge, the Upper Greensand is so obscured, and its beds appear to have become so thin and argillaceous, that all this portion of it is, apparently, of little value; and I would take, as a contributing surface, only one square mile out of eight, which is the probable extent of its exposed outcrop in this district.

These deductions, therefore, reduce the effective area of

* Still, even to within a few miles of Hitchin, slight traces of a platform at the base of the chalk hills are occasionally perceptible, and the strata are in some places arenaceous.

the Upper Greensand, westward of London, from 168 to 70 square miles.

93. *Lower Greensand.*—The contributing area of the Lower Greensand may be extended much further eastward than that of the two preceding deposits. In fact its structure throughout the whole of Kent is favourable to the infiltration of water; but as, besides the longitudinal flexures, it appears to be traversed by some important transverse fractures, we will extend the area, subject to our calculations, only as far eastward as Maidstone. This additional portion embraces 82 square miles, and makes a total of 212 for Kent and Surrey.

It is difficult to know what deductions should be made from this amount. The surface of the Lower Greensand, generally, is both bare and absorbent, but the disturbances which traverse it in an easterly and westerly direction must prevent a part of the area from contributing to the supply of water beneath London. Further, the central portion of this formation contains in Kent, and to a lesser degree in Surrey, a considerable proportion of subordinate clays; so that the mass is, properly speaking, divided into two distinct water-bearing groups. But this division is apparently not maintained in the districts northward of London. Still the separation of the upper from the lower division is, in Kent and partly in Surrey, too well marked and too persistent to allow us to imagine that the waters held in them in those districts can communicate, unless it should happen that some of the faults by which this formation is traversed, bring the disjointed edges of the lower division into contact with those of the upper, so as to allow the water from the former to pass into the latter. Consequently this lower division may possibly form a distinct water-level beneath London, so far at least as the supplies of water are concerned, which are derived from the fall of rain over the large area of sandy heaths extending along the higher part of the range of hills from Seven Oaks

and Riverhill, by Bletchingly, south of Reigate to Leith Hill and Godalming (see fig. 18, p. 94, where the position of the middle division is marked by two faint lines).

Totally excluding, therefore, on this account 120 square miles, and of the remaining 102 taking off 14 on account of minor faults and a few impermeable beds, the surface of the Lower Greensand available in Kent and Surrey, becomes reduced from 212 to 88 square miles.

In Wiltshire, this deposit, although so thin, is favourably placed as a receiving surface. It may extend over five square miles, two of which may be probably effective.

In the north-western division of the Map, the boundary of the Lower Greensand is rather doubtful. To meet the uncertainty arising from this cause I would deduct twenty square miles. Again, a drift of tenacious clay diminishing, to some extent, the collecting surface of this formation, is spread over a considerable portion of the area, especially on the south of Woburn, and on the north-east of Silsoe. It is also doubtful whether, in some parts of Cambridgeshire and in the east of Bedfordshire, a slight but broad line of elevation may not interfere with the subterranean passage of water to London. Some of the northward prolongations of the Lower Greensand, as the one north-west of Leighton Buzzard, can also scarcely be available sources of supply, on account of the probability of lateral drainage of the strata. To meet these contingencies I would further exclude 100 square miles, although this is probably an extreme allowance, and take this area at 140 instead of 260 square miles.

There is so much uncertainty attached to the extent and capabilities of the north-eastern division of the formation that I will leave it altogether out of consideration.

The result of all these deductions will be that out of 650 square miles occupied by the Lower Greensand, only 230 can be considered as an effective contributing surface.

These calculations, which are more general than I could wish, but are the only ones possible in the present state of our knowledge, show the probability that the effective areas of the several formations do not exceed:—

	Lower Tertiaries.	Upper Greensand.	Lower Greensand.
Square miles	24	70	230

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94. While upon this subject we may briefly consider whether the supplies of water, arising immediately from the fall of rain on the surface of the different water-bearing deposits, are likely to be increased by the accession of water gathered on the surface of any of the contiguous impermeable strata. But this question is so wanting in data that no definite estimate can at present be attempted. The leading points can only be indicated.

With regard to the *Tertiaries*—the chalk downs, which gradually rise above them on their southern boundary, present a surface generally too absorbent to allow much water to pass off to the outcrop of the Tertiary sands; whilst on the northern boundary of the Tertiary district, the chalk tract immediately adjacent occupies a lower level, and consequently receives, instead of contributing to, the drainage of the neighbouring Tertiaries. The drainage from the low hills of London clay may furnish to the Lower Tertiary sands, along their southern line of outcrop, a small additional supply: but, in the northern zone of outcrop, even this rarely happens, except in a few of the small transverse valleys.

95. As the chalk marl commonly forms steep slopes immediately above the *Upper Greensand*, the position of the latter is singularly favourable for receiving the surface drainage of the former deposit. The springs also thrown off from the

middle chalk at its junction with this chalk marl, must, in flowing to the lower levels, pass over this formation. The drainage from the adjacent Gault very rarely passes over the Upper Greensand, the former being almost invariably on a lower level than the latter, and the flow of water consequently determined in a contrary direction (see fig. 18, p. 94).

On the whole it is probable that the Upper Greensand receives considerable additional supplies of water from the above-mentioned sources; for the sloping surface of the chalk marl forms, in fact, a gathering ground of equal, if not greater, breadth than that of the Upper Greensand itself; whilst the outcrop of the latter constantly forms with the Lower Chalk a trough in which the surface drainage lodges. In this case, therefore, the extra supply is evidently an important element in the calculation of the water-value of this formation.

96. The position of the *Lower Greensand*, with respect to its receiving any additional supplies of water from adjoining grounds, is unfavourable. At its boundary with the underlying deposits it forms, in Kent and Surrey, an escarpment only second in prominence to that of the chalk, with which it runs parallel; and the general drainage is from this escarpment southward towards the Weald. In the same way in Buckinghamshire and Bedfordshire, the surface drainage is from the Lower Greensand northward towards the Kimmeridge Clay and Oolites. Again, along its boundary with the overlying gault, this latter formation occupies the lower level (with the exception of a limited tract near Farnham, and another near Devizes), and therefore retains the rain-water which falls upon it, and also intercepts any that may drain from off any of the strata above it. The Lower Greensand consequently appears to be restricted for its water-supply, almost exclusively to the rain falling within its own area.

§ 11. *On the Fall of Rain,—on the Quantity infiltrating beneath the Surface,—on the Power of Absorption, and on the Permeability, of the Water-bearing Strata.*

97. Before proceeding further with the geological question, it is necessary to determine the quantity of rain which falls on the exposed surfaces of the water-bearing deposits, and to inquire what proportion of it may probably pass into the interior of the strata.

The annual rain-fall in any one district varies so materially from year to year, that in order to obtain a true mean, it is indispensable that it should be taken from the results of many years. At present exact records of this description are confined to a very few places in the kingdom; but it is to be hoped that the more numerous and very complete meteorological observations, commenced within the last few years, will, at no distant period, supply this want. In the mean time we can only take the data as they exist.

98. The geographical configuration of a country leads to such differences in the amount of rain-fall even in districts nearly adjacent, that it is essential to have independent data for the area occupied by each separate geological formation. It is true that in the Tertiary district, where the physical features of the surface are not very variable, the rain-fall at a central position, as at London, might give a mean applicable nearly to the whole area; but where we have a tract of country rising to the height of the chalk escarpments, and ranging for many miles in nearly rectilinear and unbroken lines, then we may expect to find, in the Greensand districts beyond these ranges of hills, a rain-fall different to that of the Tertiary area on the opposite side of them. The evidence is at present very limited, but it points generally to an amount of rain considerably

greater in the Greensand districts of Kent, Surrey, and Wiltshire, than in the Tertiary area around London.

99. As few observations have actually been made immediately within the boundaries of the Greensands, it may be expedient for the present to take the rain-falls at the nearest adjacent places in the same geographical tract. This has been done in the annexed list.*

Geological districts.	Names of Stations.	Mean Ann. Rain-fall.	Periods of observations.	
		Inches.	Years.	Date.
Tertiary	London[1]	25·42	36	1797–1833
	Greenwich Observatory[2]	24·17	35	1815–49
	Epping[3]	26·60	10	1825–34
	Cobham, Surrey[3]	24·50	25	1825–49
	Reading[3]	25·40	17	1832–49
Chalk	Hartlip, nr. Sittingbourne[4]	32.04	3	1827-9
	Watford	25·66	9	
	Abbot's Hill, Herts[5]	26·60	8	1835–42†
	Hitchin[6]	24·28	1	1849
	Hungerford[2]	26·59	12	1838-49
Lower Cretaceous and adjacent Oolitic	Cambridge[7]	22·78	7	1838–43, 1846
	Cardington, nr. Bedford[2]	25·36	3	1847—1850
	Linslade, nr. Leighton Buzzard[8]	23·16	1	1849
	Aylesbury[2]	25·70	2	1848-9
	Oxford[9]	23·15	20	1828–47
	Bath[10]	32·79	8	1842–49
	Beckington, nr. Melksham[2]	31·80	3	1847–49
	Selbourne, nr. Alton[11]	37·20‡	9	1802 (before)
	Uckfield[2]	27·60	3	1847–49
	Reigate	30·00§	8	1820–27
	Maidstone[12]	28·94	1	1849

[1] Luke Howard's "Climate of London." [2] For these lists I am indebted to the kindness of Mr. Glaisher of the Greenwich Observatory. [3] Beardmore's "Hydraulic Tables." [4] Mr. Bland. [5] Mr. Dickinson. [6] Mr. Lucas. [7] University Observatory. [8] Mr. J. Osborn. [9] Radcliff Observatory. [10] Mr. R. Biggs. [11] Cited by Dr. Dalton. [12] Dr. Fielding.

* I have since received the following rain-falls for 1850,—Greenwich, 19·7; Hitchin, 20·56; Cardington, 18·5; Linslade, 20·91; Uckfield, 28·8; Maidstone, 23·36. The fall this year was generally much below the average. The fall in 1849 may be taken as a fair average; at Greenwich it amounted to 23·9.

† Since continued to 1849, see Proc. Inst. Civ. Eng. Vol. IX. p. 158.

‡ This quantity is, for a mean of 9 years, so large, that there is probably some error. I have therefore omitted it in the general averages.

§ The observations are lost, and the rain-fall is given from recollection. It is stated to have been rather above 30 inches.

From these observations the following approximate mean results may be deduced, by taking an average of the rain-fall at stations in, or surrounding, the several geological districts,—those nearest on either side being combined to form a mean.* Thus the rain-fall at and near Devizes is taken as intermediate between the fall at Hungerford and Beckington; while that at and round Wallingford, is assumed to be intermediate between the fall at Oxford and that at Reading. For the Tertiary district and the chalk, the average is that of all the places named taken together. In the Greensand districts, as the several areas are detached and wide apart, a separate calculation is made for each. This must be viewed only as a temporary measure until more complete data are obtainable.

Stations serving to form the averages for the several districts.	Mean Ann. Rain-fall. Inches.[2]	Geological district represented.
London, Greenwich, Watford, Epping, Cobham, Reading	25	*Tertiary.*
Hartlip, Cambridge, Greenwich, Watford, Abbot's Hill, Hitchin, Hungerford, Reading	26	*Chalk.*
[1]N. Hitchin, Aylesbury, Oxford, Reading ..24·75 W. Hungerford, Beckington, ...29·20 S. Reigate ....30·00	28	*Upper Greensand.*
N. Cambridge, Bedford, Linslade, Aylesbury 24·25 S. Reigate, Uckfield, Maidstone ....28·84	26½	*Lower Greensand.*

[1] Position of the zone of outcrop with reference to London. [2] In round numbers.

100. *We have next to inquire what proportion of the rain-water may pass from the surface into the interior of the strata.* This is a subject involved in much obscurity; very few experiments have been made, and these at first sight appear rather contradictory. In 1796-8 Dr. Dalton made, at Manchester, the first series on which any dependence could be placed.† The

* In Johnson and Berghaus's Physical Atlas (Map, Meteorology), the line of 25 inch rain-fall runs by Herne Bay, passes at a short distance to the south of London, and then sweeps round by Oxford; whilst the 30 inch line of rain-fall proceeds from Dover, by the north of Portsmouth, to Bristol.

† "Experiments and Observations to determine whether the quantity of rain and dew is equal to the quantity of water carried off by rivers and raised by evaporation,

apparatus he used was a vase in the form of a pluviometer, 10 inches across at top and three feet deep, into which he put "a few inches of sand and gravel," and then filled it up with "good fresh soil." A pipe at the bottom of the vase conducted the water which filtered through these materials into a graduated receiver. This was placed in the ground with an ordinary pluviometer by its side, and left undisturbed for three years — the grass being allowed to grow over the surface.

The next, and more complete series of experiments, were those performed by Mr. Dickinson at Abbot's Hill, near Hemel Hempstead.* They extended over a period of eight years (1835-43), and were conducted on the same plan as those by Dr. Dalton. The cylinder was filled with the "soil of the country, a *sandy gravelly loam.*"

Mr. Charnock's experiments were made near Ferrybridge, and continued during five years.† The cylinder was filled with two feet of "gravel and sand, capped by soil."

101. The following are the results of these several experiments :—

Observers.	Mean Annual fall of rain on the surface during the period the experiments were continued.	Mean Annual quantity of rain filtered through the 3 feet of ground.	Proportion per cent.
	Inches.	Inches.	
Dr. Dalton	33·55	8·39	25·0
Mr. Dickinson ..	26·6	11·29	42·4
Mr. Charnock ..	24.60	4·82	19·6

It must be observed in explanation of the apparent discrepancies between these results, that Dr. Dalton used the common surface soil of the district (New Red Sandstone), which contains a good deal of clay, and would probably be very

with an inquiry into the origin of springs." Memoirs of the Literary and Philosophical Society of Manchester, Vol. V. part II. p. 346.

* Proc. Inst. Civil Eng. Vol. II. p. 168 ; 1843. Since these pages were written a further account, bringing the experiments down to 1849, has been published in the 9th vol. of the same work, p. 158. The infiltration during this latter period was rather less.

† Journ. Agric. Soc. Vol. X. p. 516.

absorbent and retentive; Mr. Dickinson took the lighter gravelly loam overlying the chalk, and common in the Tertiary and Secondary districts around London; whilst Mr. Charnock employed the heavier magnesian limestone soil of Yorkshire,—and further, his experiments having reference to a special agricultural question, the soil was occasionally stirred. In this latter instance, therefore, the evaporation from the surface would be increased, which, joined with the fact of this soil being much more argillaceous, would account for the infiltration of water being so much less than in the other experiments.

102. From calculations over large areas it would appear that about one-half of the rain which falls is lost by evaporation and taken up by vegetation, and that the other half drains on the surface or passes into the ground. In cultivated districts of similar climate the indirect evaporation produced by vegetation may remain on the average nearly the same; but the quantity of water returning to the atmosphere by direct evaporation, or passing into the river channels by surface drainage or carried off underground, depending entirely upon the lithological character of the country, must necessarily be subject to extreme variations. If, in fact, the above proportions can be considered a fair mean, then, as there are many soils which allow of little water filtering through them, and on which the evaporation and surface-drainage would be great, so there must be, to maintain an average, cases in which the larger portion of the rain is absorbed into the strata.*

* In the Annuaire du Bureau des Longitudes, for 1835, M. Arago gives an account of some experiments made on the quantity of water carried to the sea by the Seine. He observes (p. 198) that "The volume of water which passes annually under the bridges at Paris is scarcely a third of that which falls as rain in the basin of the Seine above Paris. Two thirds of this rain either returns into the atmosphere by means of evaporation, or goes to the support of vegetation and of animal life, or is conducted to the sea by subterranean channels."

The experiments which have been made upon the quantity of water carried to the sea by the Thames appear to be too uncertain to be depended upon. See Rennie's Report in Trans. Brit. Assoc. for 1835, p. 488.

103. Of the rain-fall, which passes by infiltration into the ground, the proportion is very variable at different seasons of the year. Mr. Dickinson's experiments show that in the six months from April to September inclusive, a very small quantity of rain-water traverses the surface soil. It is in the heavy and long continued rains of winter that the chief infiltration takes place. The following list gives the monthly results of the eight years' observations from 1835 to 1843.*

	Mean fall.	Mean infiltration.	Per cent.
January	1·847	1·307	70·7
February	1·971	1·547	78·4
March	1·617	1·077	66·6
April	1·456	0·306	21·0
May	1·856	0·108	5·8
June	2·213	0·039	1·7
July	2·287	0·042	1·8
August	2·427	0·036	1·4
September	2·639	0·369	13·9
October	2·823	1·400	49·0
November	3·837	3·258	84·9
December	1·641	1.805	100·0

104. The preceding experiments have reference, however, merely to the *mixed surface soil.* They show a considerable variation in its facility of transmitting water; but they do not give data respecting the permeability of the *undisturbed strata* themselves. The relative power of the two must differ; in the latter it varies much more than in the former. In order to obtain data bearing upon this point and also for the purpose of determining the quantity of water which a given bulk of arenaceous strata would hold, I made a few experiments, of which the table in p. 114 gives the main results.

From them it would appear that a cubic foot of arenaceous strata can hold from about $1\frac{9}{10}$ to rather more than 3 gallons of water, or from about two-sevenths to one-half of its bulk; and that the facility with which water passes through

* Parkes in Journ. Roy. Agric. Soc. Vol. V. p. 147.

† Part of the Nov. fall infiltrates in Dec.

Table showing the absorbent Power and *relative* permeability of the principal Water-bearing Strata.*

Formation.	Division.	Place of Specimen.	Lithological Character.	Quantity of water absorbed by 1 cubic foot.†		Quan. permeating through equal portions of the sands in 1 hour.
				Cubic Inches.	Gallons.	Cubic Inches.
Lower Tertiary Strata	Upper	Hertford	Fine sand, light coloured, slightly argillaceous	669	2·41	1·8
	"	"	" " rather more argillaceous ..	712	2·56	
	"	Croydon	Coarse mixed bright green and yellow sand	626	2·25	5·7
	Middle	Charlton	Fine sand, light ash yellow	723	2·60	5·1
	Lower	Croydon	Very fine light coloured sand, rather argillaceous ..	774	2·79	1·5
Upper Greensand	Upper	Devizes	Very fine and argillaceous sands, light green	853	3·07	3·6
	"	"	" rather less argillaceous, and greener	821	2·96	
	"	Gatton	Very fine, and argillaceous, light green sand......	842	3·03	1·2
	"	Godstone	" more argillaceous "	883	3·18	
Lower Greensand	Upper	Limpsfield	Very fine, white and pure siliceous sand	518	1·87	9·6
	"	Chilworth	Fine, bright ochreous "	615	2·21	18·0
	"	Leighton	Bright ferruginous sand " rather coarse..	712	2·56	14·4
	Lower	Reigate	Fine yellow sand, slightly argillaceous	734	2·64	4·8
	"	Chilworth	Rather coarse light greenish sand	605	2·18	7·5
	"	Betchworth	Very coarse sand with small pebbles of quartz	605	2·18	8·4

A common garden mould overlying ochreous flint gravel at Clapham Common I found to absorb 2·60 gallons of water per cubic foot.

The specimens in the above list were all taken from the ordinary sandy beds of the several formations—such as when dry form sandy surfaces. Even when wet the most argillaceous of them does not form a tenacious paste with water. In parts of Berkshire an upper bed of the Upper Greensand, frequently contains much less clay than the specimens above: I have been unable to return to the spot to procure a specimen of it. The lowest bed is also often more sandy and permeable than these.

* The experiments on the absorption of water were made with portions of sands measuring 40 cubic inches; the specimens were well dried, and a measured quantity of water then added, until they were fully saturated without alteration of bulk. The permeability, which is only shown relatively, was determined by measuring the quantity of water that passed through 15 inches of the different sands, in a glass tube $1\frac{1}{4}$ inches in diameter and bent at right angles, under a pressure of 6 inches of water in the longer branch of the tube.

† A cubic foot contains 1728 cubic inches, or 6·232 gallons.

these different strata varies as from 1 to 10. It is also evident that it is not the purest sands which hold the most water. The presence of clay increases the capacity for water, at the same time that it rapidly diminishes the permeability of the strata,—a very small quantity appearing to have great influence in this respect. The strata which, in these experiments, unite the greatest absorbent power and permeability combined, are those consisting of clear siliceous sands, with grains about the size of clover seed. When the grains are very fine they hold less water. The coarsest sands being mixed with a small quantity of clay, their real permeability is not known.*

These experiments give in round numbers the following mean average results for the three water-bearing deposits.

	Quantity of water that one cubic foot can hold. Gallons.	Permeability—taking the Tertiary sands as unity.
Lower Tertiary Sands	2½	1·00
Upper Greensand	3	·68
Lower Greensand....	2¼	3·00†

105. In endeavouring to combine these results with the permeability of the surface soil as exhibited in the experiments of Dr. Dalton and Mr. Dickinson, I experienced considerable difficulty; and even now can consider, as approximate and probable, the conclusions relative to the Lower Greensand only. In trying the rapidity with which water passed through garden mould, in the 15 inch tube, I found it to be not

* Some experiments by Prof. Schübler make the power of soils to contain water to be, according to volume, as follows:—

Siliceous sand	37·9	per cent.	Loamy clay	57·3	per cent.
Calcareous „	44·1	„	Garden mould	67·3	„
Sandy clay	51·4	„	Arable soil	57·3	„

Journ. Roy. Agric. Soc. Vol. I. p. 177, 1840.

† The number for its upper division is about 4·00, and for its lower 2·00.

more than 1·8 cubic inch per hour, which is less than the average of any of the strata.* But with a zinc cylinder 1 foot deep, nearly 4 inches in diameter, and filled with about 120 cubic inches of several sands, the relative results were different;—the proportion of water filtering through the Tertiary sands and the Upper Greensand was much less, whilst through the garden mould, on the contrary, a much larger proportion passed. The permeability of the latter, in fact, in this case considerably exceeded that of either of the former; it however still held in this other set of experiments the same relative proportion to the sands of the Lower Greensand.†

106. If, therefore, we combine these results, taking the permeability of the soil at the maximum indicated in these latter experiments, and compare it with the Lower Greensand under the same conditions,—and then again take this with reference to the other deposits, according to the results obtained in the first experiments,—the comparative permeability

* With regard to the retentiveness of soils, Professor Johnston, states in his "Lectures on Agricultural Chemistry and Geology" (2nd Edit. 1847, p. 533,) that from 100 lbs of dry soil water will begin to drop, if it be a—

Quartz sand, when it has absorbed .	25	Pounds	of water.
Calcareous sand	29	"	"
Loamy soil	40	"	"
Chalk	45	"	"
Clay loam	50	"	"
Pure clay	70	"	"

The rate of percolation is not given.

† These experiments I do not detail, as it would be desirable to repeat them, as well as those in the first list, and also to give them some other form.

The surface mould, although transmitting water, when saturated, with as much facility as the Upper Greensand, imbibed it far less readily when dry. It took in fact more than three times longer to saturate the former than the latter. The relative time required for the saturation of equal quantities (*i.e.* 15 inches in the glass tube) of the different strata stood thus—

Lower Tertiary sands . .	26	minutes.
Upper Greensand . .	32	"
Lower Greensand . . .	6	"
Garden mould . .	more than 100	"

of the different deposits will be exhibited by the following numbers, taking as unity the permeability of a surface soil from Clapham Common.

Surface soil.	Tertiary sands.	Upper Greensand.	Lower Greensand.
1·00	1·73	1·02	4·50

It would accordingly appear that, on a bare surface of the sandy portions of the Upper Greensand, water infiltrates with about the same facility as through a rather porous vegetable soil, on the Tertiary sands nearly twice as rapidly, and on the Lower Greensand $4\frac{1}{2}$ times more rapidly.

107. The experiments of Mr. Dickinson show that about $\frac{4}{10}$ths of the rain-fall can pass through 3 feet of the ordinary surface soil.* Its further progress depends upon the nature of the subsoil. Clays would stop altogether the further descent of the water, while sands would offer little or no impediment. But, as some portion of the Tertiary sands, and a very large proportion of the Upper and Lower Greensands, present denuded surfaces, without gravel and only with a few inches or foot of mould partaking of the sandy character of the underlying beds, the passage of the water, from the surface downwards, would depend almost entirely upon the lithological character of these deposits.

On the Tertiary sands the quantity of rain absorbed would consequently be likely rather to exceed $\frac{4}{10}$ths of the fall, whilst on the Upper Greensand, that proportion may be applicable to the whole effective area. In the Lower Greensand the absorbent power of the strata is so very much greater, that a large proportion of the total rain-fall must pass into the body of this formation.

* I refer to these experiments because the surface soil at Abbot's Hill would more nearly resemble that spread generally over the Tertiary and Secondary strata around London, than would that of Manchester, which is formed in greater part from the debris of the sand stones, clays, and marls of the New Red Sandstone. Mr. Dickinson considers that when the rain water has passed to a depth of 3 feet beneath the surface, no further loss by evaporation takes place.

108. But we have also to take into consideration that, however absorbent the surface soil may be, the existence of vegetation, to which we have before alluded, must intercept a large portion of the rain-fall. This has been partially allowed for in the experiments of Dalton and Dickinson, in both of which the surface was covered with a growth of grass. But this is hardly enough; the more active and vigorous vegetation of the corn crops and of trees is productive of a far greater evaporation. What it may amount to has not yet been determined by a sufficient number of direct experiments. As an indication of the importance of vegetation in absorbing the rain-fall, I may mention that a tree of average size is supposed to yield by evaporation from its leaves about 2 to $2\frac{1}{2}$ gallons of water daily; and in some recent interesting experiments of Mr. Lawes,* three plants of wheat or barley grown in pots gave off in the course of six months of their active growth nearly $1\frac{1}{2}$ gallon of water;—for every grain of dry produce 200 grains of water were evaporated. We have, however, to add to the ordinary supply of water by rain, that afforded by dew and the absorption of moisture from the atmosphere by

* "On the amount of water given off by Plants during their Growth," Journ. Hort. Soc. Vol. V. part I. 1850. In applying these experiments to any given area, the evaporation from each plant will depend very materially upon the thickness of the crop on the ground. The amount of evaporation is best determined by the quantity of dry produce. Mr. Lawes observes with regard to wheat, barley, peas, beans, and clover, " that in every case more than 200 grains of water passed through the plant, for 1 grain of material (substance of the plant) accumulated." Now this will enable us to form some general estimate of the evaporation caused by the same description of vegetation on any given area. Prof. Johnston, in his work above quoted, calculates, p. 927, that the average gross produce per acre of different crops approaches to the following quantities :—

	Bushels.		Average weight in lbs.		Average weight of straw in lbs.		Total. lbs.
Wheat	25 to 30	=	1750	+	3300	=	5050
Barley	35 — 40	=	1985	+	2300	=	4285
Beans..........	25 — 30	=	1700	+	2950	=	4650
Peas	25	=	1650	+	2700	=	4350
Clover	2 Tons	=	4480			=	4480

To these totals we have to add the weight of the stubble and roots, which may be taken roughly at one half the weight of the straw (Johnston, p. 745-6, and Boussin-

argillaceous soils,* amounting together, probably, to several inches annually.†

As the Lower Tertiary strata and the Upper Greensand commonly form arable lands, they are most affected by these causes. The Lower Greensand, with a portion of such lands, presents also a considerable breadth of heath and wood.

These remarks are made more to guard against assuming an increased infiltration proportioned to the greater porosity of the strata, rather than to diminish very materially for the underlying strata, the proportions established by Mr. Dickinson's experiments for the surface soil; for in these experiments almost all the infiltration took place beween October and March inclusive, while none comparatively occurred during the summer months when the rain appears to have been dissipated by direct evaporation and vegetation. The influence, however, of these agencies diminishes as the soil becomes more sandy, the rain-water being more rapidly removed from their influence.

gault's Rural Economy, Law's translation, p. 480-8), and then, as I am informed by Mr. Lawes, to subtract one-seventh of the weight, as harvested, for water. We shall then obtain the following approximate results. The rain-fall we may suppose to be 25 inches, which is equal to an annual fall of 564,934 gallons of water per acre, or 357, 911, 335 per square mile,—

	Evaporation of water during growth.	
	Per acre. Gallons.	Per square mile. Gallons.
Wheat	114,860	73,510,400
Barley	93,180	59,635,200
Beans	105,000	67,200,000
Peas	97,720	62,540,800
Clover	115,380	73,843,200

* According to Schübler during a night of 12 hours and when the air is moist,

1000 lbs of a	perfectly dry	Quartz sand	will gain	0	Pounds.
„	„	Calcareous sand	„	2	„
„	„	Loamy soil	„	21	„
„	„	Clay loam	„	25	„
„	„	Pure agricultural clay	„	37	„

Johnston's "Lectures on Agricultural Chemistry and Geology," p. 532.

† The fall of dew at Manchester was estimated by Dr. Dalton at 5 inches annually.

109. After making due allowance for the operation of all these causes, we may, I think, conclude that, as the proportion of rain-fall passing through the ground amounts in Mr. Dickinson's experiments to 42 per cent, the absorption by the different water-bearing strata, within their *effective* areas, is probably not less than:—

	Total mean annual rain-fall.	Amount of infiltration.	
	Inches.	Inches.	per cent.
Lower Tertiary Sands	25	12 or	48
Upper Greensand	28	10 or	36
Lower Greensand	26½	16 or	60

§ 12. *On the relative Volumes, Dimensions, and Capacity for Water, of the several Water-bearing Strata.*

110. In the foregoing pages a general account has been given of the geological structure of the country around London, with reference to the conditions which determine the water-bearing capacity of the several deposits, and to the rain-fall upon each of them. We now have to inquire, by a comparison of the dimensions and relations of these strata, as to the quantity of water that may be probably obtained from the different groups.

In estimating the fall of rain on the areas of the water-bearing strata, we must allow for the limitations and deductions pointed out in § 10, and to which, as their influence is undoubted, numerical values, necessarily in a great degree arbitrary (and which I only submit as an approximate measure of certain probabilities), have been assigned. In the

following calculations, we take, therefore, only the presumed effective areas of the different deposits,—that is to say, their total areas diminished by the agency of all those conditions of position and structure, which interfere with the absorption of water at the surface, and its transmission within the mass of the strata.

111. Allowing for these considerations, the mean daily* fall of rain on the several surfaces, and the total probable quantities absorbed into the interior of each formation, will be as indicated in the following Table.

	Probable extent of effective area.	Quantity of rain water received.		Probable quantity absorbed	
	Square miles.	Inches annually.	Gallons in 24 hours.	Inches annually.	Gallons in 24 hours.
Lower Tertiaries ..	24	25	= 23,749,656	12	= 11,411,352
Upper Greensand ..	70	28	= 77,660,660	10	= 27,735,960
Lower Greensand ..	230	$26\frac{1}{3}$	= 241,500,920	16	= 145,811,720

112. Assuming these to be the approximate quantities of water which the three water-bearing deposits respectively receive and imbibe in a given time, we have now to measure the volumes of the strata themselves, so as to arrive at the quantity of water which they may hold, for upon this will depend the permanent and steady maintenance of the supply they may afford.

In calculating the dimensions of the strata in their subterranean range under the London clay and the chalk they must be taken, as in the case of the superficial areas, not at their full dimensions, but only to the extent to which they may be supposed to communicate with a centre beneath London.

With regard to the Tertiaries and Upper Greensand, we

* I take the *daily* in preference to the *annual mean*, as the numbers are more simple and more immediately applicable, as a term of comparison, to the general question of the water-supply.

may confine our attention to that portion of them which lies west of a meridian passing through Deptford, and embracing the north-western and south-western divisions of the Map. The available subterranean area of the Lower Greensand extends, however, beyond these limits, and may be prolonged eastward as far as a line carried from Maidstone* to Cambridge.

On the west of London, the subterranean area of the water-bearing sands of the Lower Tertiaries may be considered as limited by a line passing from Guildford to Maidenhead; while the Upper and Lower Greensands have an available range westward as far probably as Devizes and Calne. It may, however, be as well to exclude the Upper Greensand north of a line drawn through Stevenage and Luton, and the Lower Greensand west of a line drawn from Alton to Abingdon (¶ 68 and 81).

113. The thickness of the permeable portion of the several water-bearing deposits has already been calculated (¶ 27, 67-71 and 78) for the whole area; but it is necessary now to take the average thickness from that portion of them alone, which is limited to the areas above defined. That of the Tertiaries is a mean deduced from an equal number of sections on their northern and southern outcrops, and on a central line between them. In estimating the dimensions of the Lower Greensand, the lower division of this deposit in Kent and Surrey, but not that in the counties north of London, is excluded for reasons assigned in ¶ 74 and 78.

If then the underground areas of the strata, taken with these limitations, be multiplied by their thickness, we shall have their volumes, in numbers, each unit of which will represent a mass one mile square by one foot thick.

* It might probably be even extended eastward of this town.

	Thickness of permeable beds.		Available subterranean area.		Volumes.
	Feet.		Square miles.		
Lower Tertiary Strata	19	×	520	=	9,880
Upper Greensand	30	×	2840	=	85,200
Lower Greensand	200	×	4600	=	920,000

114. The quantity of water which may be held in masses of these dimensions, depends, as before mentioned (¶ 104), upon the texture of the sands, and on the fissures and closeness of bedding of the more solid and less permeable beds.* Taking their capacity as previously (p. 115) determined, it would appear that the quantity of water, below the line of water-level (see fig. 18, p. 94), in each block one mile square by one foot thick, as well as over the whole effective superficial area (p. 106) taking the same thickness, is as follows :—

	Gallons per block of strata 1 mile square and 1 foot thick.	Gallons in a thickness of 1 foot, extended over the whole of the effective superficial area.
Lower Tertiary Sands	69,696,000	1,672,704,000
Upper Greensand	83,635,200	5,854,464,000
Lower Greensand	62,726,400	14,427,072,000

All the permeable beds below the level of the water-line (s, s', x, s'', fig. 18) must be in this condition of saturation. The immense extent of the reservoir formed, therefore, by the Lower Greensand may readily be conceived, when it is considered that each of the 920,000 portions contains probably at least 60,000,000 gallons of water. Capillary attraction and friction would necessarily cause the retention of the larger portion of this quantity, but still that which may be considered free must be excessively large.

With respect now to the passage through the mass of the

* I refer to some beds of the Upper Greensand, which are too closely associated with the sands to be excluded. There are also some few compact beds of the Lower Greensand.

strata of the large bodies of water which thus appear to be stored in them. It has been shown that their capacity for water varies considerably, and also that it passes through the arenaceous beds with very different degrees of rapidity. The one property appears to be in some measure inversely as the other.

115. At first, the transmission of the water, being effected by gravity only, is slow and impeded by the capillary attraction of the sands, as well as by friction. But in the more deeply-seated portions of the strata, extending from 500 to 1000 feet beneath the surface, the hydrostatic pressure must be so great as to force water with comparative facility through beds, in which near the surface it is transmitted very slowly. It is probable that, under these conditions of depth and pressure, the water will flow through loose arenaceous strata with a rapidity and ease far exceeding that of any delivery near the surface.

116. The next question regards the distribution and mode of escape of the large quantity of water, which infiltrates on all parts of the exposed surface into the interior of deposits consisting essentially of sands. This is effected 1—by a constant issue in the form of springs; 2—by a nearly equally constant oozing of moisture in quantities, separately small, but large in the aggregate, at the junction of the beds of sand and clay; 3—by a superabundant discharge from these two sources after wet weather, and during the winter months; 4—by an exceedingly slow movement underground, when any escape at distant points, and on lower levels, can take place.

As the first mentioned of these causes supplies most of the brooks and streams within the districts formed by the water-bearing strata, any interference with its right and sufficient action should be avoided.

It is by a proper adjustment in preventing the loss of water

arising from the operation of the last three causes, which, I believe, dispose of a very large portion of the water infiltrating beneath the surface, that an underground source of supply, available for Artesian wells, is to be looked for. What the quantity may be, could be roughly estimated by gauging in their ordinary state the streams rising in the district; calculating the quantity required for vegetation; and determining the amount supplied by rain. The difference between the last and the sum of the first two quantities will give the approximate proportion of water lost by evaporation and floods. Part of this must always unavoidably occur; but when the difference appears disproportionately great, then there is probably an unnecessary waste arising from an over-saturated condition of the arenaceous strata, which by keeping all the lower marginal beds moist and wet, forms an evaporating surface of very considerable extent: of the importance of this agency some conception may be formed, when we consider that by its means alone the quantity of water often returned to the atmosphere from one square mile of such surface may amount, according to some calculations which have been made, to as much as 400,000 to 500,000 gallons daily.

If Artesian wells were established in the Lower Greensand beneath London, their action would tend to lower slightly the line of water level (*s*, *s'*, *x*, *s''*, fig. 18, p. 94) so that a larger quantity of water could be added to it from the surface, without a general overflow to the same extent as before, and a large annual amount, now running to waste, might probably be retained and stored in the strata. At the same time no great depression of the line of water-level, such as would interfere with the more local issue by springs, need be necessary. For this line forms a curve rising many feet above the points at which the springs issue at *s* and *s'*, and the summit of this curve may fluctuate within certain limits without its extremities being materially affected. Such changes would be attended

with important results, for a clear fall* throughout the whole of the effective area (230 miles) of the Lower Greensand, even of 1 foot at the summit, lessening until it becomes imperceptible at the margin, of the curve, or of 6 inches uniformly, would be equivalent to the disengagement of 7203 million gallons of water, or to a supply of 50,000,000 of gallons daily, for a period of nearly five months, independently of any replenishing by rain.

A rather greater fall in the water level at the end of the summer months than now occurs, being equivalent to an increase in the dimensions of the reservoir, would enable the water-bearing strata to receive and store much of the surplus winter waters, now lost by floods.

Not only is the quantity, carried away at these periods in the surface channels, large, but in this case also as large breadths of water remain exposed for a time on the surface the loss by evaporation is very important. On such occasions the water overflows at intervals along the whole length of the marginal edge of the Lower Greensand at its junction with the Gault, and running down upon the surface of the latter often helps to flood the valleys extending to the base of the chalk escarpment; for these floods probably arise as much from this cause, as from an accumulation of surface drainage, merely on the impermeable beds of the Gault itself, or on the Lower Chalk marl.

117. These calculations, although offered only as very general approximations, give results sufficiently marked and decided, that even admitting the necessity of not inconsiderable corrections, I think they establish strong *primâ facie* evidence in favour of the Upper and Lower Greensands beneath London

* In speaking of any fall of the line of water-level, I mean the transit for that distance of the water throughout the body of the strata,—not the variation in the exact surface line, which does not move with equal freedom and does not give a well-defined outline.

containing unusually large quantities of water, which, it will be shown further on (§ 14 and 15), may be rendered, without difficulty, available for the supply of the Metropolis by means of Artesian wells. What their yield might be could only be determined exactly by actual experiment; but judging from analogy, if the Lower Tertiary sands, with dimensions comparatively so limited, can nevertheless furnish not less than 3,000,000 to 4,000,000 gallons of water daily (and if, as is probable, they supply much of the water found in the upper beds of the chalk beneath London, their yield may amount to 8,000,000 or 10,000,000), then I submit that there is a reasonable probability, after allowing for the present over-drainage of the Tertiaries of the Upper Greensand,—with an effective area and a thickness three times greater than those of the Lower Tertiaries,—yielding daily, and without diminution, from 6,000,000 to 10,000,000 gallons; and of the Lower Greensand,—which exceeds by ten times the Lower Tertiaries in both these respects,* — yielding from 30,000,000 to 40,000,000 gallons of water in the 24 hours, taken at about the surface level. This is more especially probable with regard to the Lower Greensand, when its extreme permeability in comparison with that of the Lower Tertiary sands is considered, and would tend, with other causes, to give it an additional value beyond that which is here assumed.

The height of the outcrop of the Greensand has also to be taken into account; it is such that it would cause a much more rapid discharge of water at London than can be effected by the Tertiary sands (see § 15).

* It is also to be observed that probably none of the water passing into the Greensands is lost by transfer to other deposits, as both of these are confined between perfectly impermeable strata; whereas there can, I think, be little doubt that much of the water from the Tertiary sands passes into the chalk. It is not impossible, however, that the pressure of the water in the chalk along the marginal edges of the Tertiary sands may, in some places, and near the surface, establish a flow of water from the former into the latter deposit.

V.—THEORETICAL CONSIDERATIONS.

§ 13. *Effect of Disturbances of the Strata on the subterranean passage of Water.*

118. I HAVE used the term "disturbances" to signify not only *faults*, or fractures of the strata, but also to indicate *lines of flexure** or *curve.* There is, however, this (for our object) essential difference, that in the one case the disturbance breaks, whilst in the other it does not break, the continuity of the strata.

The primary effects usually of disturbing forces is rather to bend and contort the strata; and it is only as a secondary result, when the tension becomes sufficiently great that the disturbed mass is broken, and *faults* produced by the disjointed portions of the strata being forced to different levels. But the same difference of level may be equally caused, although not so suddenly, by the mere operation of the curves and flexures; and this I am convinced is the more ordinary form of disturbance exhibited in the strata around London (fig. 16).

I particularly allude to this point because it materially affects both the underground transmission of water, and the thickness of the Chalk and Greensands. The main line of dis-

* This term was, I find, used by Mr. Hopkins, of Cambridge, in his Paper "On the Structure of the Wealden," as also the general term "lines of elevation." They appear to me more correct and expressive of the true meaning than the term "lines of fault." I would refer to this important paper of Mr. Hopkins for the description of the *disturbances* affecting the district adjacent to, as well as part of, that described in these pages, and more especially for an inquiry into the theory of the phenomena; he considers that a large proportion of the disturbances of the Wealden are lines of flexure and not true faults. Trans. Geo. Socl. Vol. VII. p. 1, 1845.

turbance is that forming the axis of the weald of Kent and Surrey,—parallel to which, and therefore in a general east and west direction, we find, in receding from it, a succession of descending curves, extending at intervals to the Tertiary district. The principal ones are represented in the Section No. 1 on the Map, but the scale is there almost too small to show them clearly. Their general form is better seen in fig. 18, p. 94.

These flexures of the strata generally run in long and nearly straight lines, maintaining a near parallelism one with the other, and are occasionally accompanied by faults, usually of small size, and of limited range and extent; they are separated by zones, in which the strata remain nearly horizontal. I have marked the course of a few of these disturbances on the Map. My object is, however, rather to show their approximate position, and to indicate by short parallel lines the probable occasional breaks in the strata, than to lay down any specific fracture.

The Brighton Railway traverses at right angles a series of these curves between New Cross and the Reigate station. They commence at the New Cross cutting, with a flexure in the strata, whereby the Lower Tertiary strata are brought to the surface. The London clay then continues nearly horizontal to Croydon, where, in the first cutting beyond the station, the chalk rises to the surface by a rapid curve. Between the tunnel and the Merstham station another curve brings up the Upper Greensand and the Gault at an angle of 18° to 20°; and in the same manner the lower beds of the Lower Greensand crop out in the cutting at the junction of this line with the Dover one. The strata in all the intermediate districts are comparatively level.

119. If we follow the curves along the lines of their course, or their *strike* (as it is termed by geologists), we shall find

them to vary very considerably in their angle and elevation, even within short distances. Thus one of the great lines of flexure running parallel with the escarpment of the North Downs, is shown at *y* in fig. 18. It there tilts up, at a moderate angle, the Chalk, Upper Greensand, Gault, and the Lower Greensand,— its protruding effects ceasing midway (taken transversely) in the latter, where the strata resume their nearly horizontal position until affected by another curve (*z*). This arrangement of the strata exists in the parallel of Nutfield and Bletchingley. If the disturbance had been stronger, or the resistance less, then the curve at *y* would have been greater, and the strata *g* might have been brought to the surface in the valley at *s*′, as they actually are at Pease Marsh, one mile south of Guildford. Westward of this town the same flexure tilts up the ridge of the Hogsback at a steep angle, while its easterly course is very apparent for some distance towards, and again beyond, Dorking. As these curves recede from the main axis of the weald, they appear to take larger and more easy sweeps. They are not always continuous, often subsiding where an adjacent one becomes more developed. Neither are they necessarily parallel,—there are several exceptions, although that is the prevailing rule.

All the main lines of disturbance maintain this general east and west direction. The few which run at right angles to them are small, and consist rather of actual fractures and breaks of the strata than of flexures and curves.

120. The disturbances which have been shown to exist in the Tertiary area, have of course affected the underlying secondary deposits. Denudation, however, has removed a portion of the Lower Tertiary beds, raised by these disturbances above the general level of the surface; and their continuity being thus in many instances broken, the passage of water, from one district to another, is often prevented (¶ 39 and 40).

But in the case of the deep-seated strata of the Upper and Lower Greensands, these disturbances would not materially interfere with the subterranean passage of water, in consequence of their mass being entire, and of their depth beneath the surface. For it is evident that, if the lower cretaceous strata form a series of constantly descending curves, from their outcrop to a line drawn longitudinally through the centre of the Tertiary area, the crest of each ridge being lower than that of the preceding one, the hydrostatic pressure will force the water down each successive fall, and over the summit of each intermediate curve, — provided that in no case the summit of any of these curves rises to the level of the one which brings the strata to the surface.

When, however, the strata are fractured and shifted, the transmission of water will be interrupted wherever the difference of level produced by the fault exceeds the thickness of the water-bearing deposit, as may probably happen in the Upper Greensand, along the line of the "north and south" line of disturbance of the Lea and the Ravensbourne. But when any part of the disjointed permeable strata remain in contact, the water-communication may, notwithstanding the fracture, still be efficiently maintained. Thus the numerous small faults and fractures visible in the Tertiary strata at Lewisham, Deptford, and elsewhere in that neigbourhood, do not appear to be in any instance of sufficient magnitude to destroy the continuity of the thick Lower Greensand strata beneath those places.

121. The causes, therefore, which tend to restrict the free passage of the water in the underground area of the Lower Tertiary sands, would be comparatively inoperative in the deeper seated and far thicker beds beneath the chalk, which may be practically considered as allowing, so far as faults are concerned, of the nearly free transmission of water. And as the subterranean strata of the Upper and Lower Green-

sand receive supplies of water by means of their outcrops in various directions, and all converging to that central area of greatest depth, which extends beneath London and the district a few miles westward, the water withdrawn there would be replaced by an influx from all parts of the communicating circumference to this centre.

Not that there would necessarily be in all these cases an equal, or perfectly free transmission,—but that, after allowing for all possible impediments, the probability is that, with a few local exceptions, the Greensands still remain sufficiently entire to allow of the passage of water, throughout the greater part of their subterranean range.

122. It also further appears that the underground waters very commonly tend to take a course corresponding in a great measure with that of the waters above ground; that streams and rivers may be considered as representing, in definite lines on the surface, a water-flow agreeing in its general direction with that which takes place, bodily, in the strata below. M. D'Archiac,* who has paid great attention to the subject of the water-bearing strata of the Tertiary and cretaceous series of France, confirms, as the result of his experience, the rule laid down on perfectly independent grounds by the Abbé Paramelle, in his Observations on Springs, viz., "That the subterranean currents of water follow the same "law (with reference to their course), as those which flow on "the surface."

This arises from the great physical features of the surface, having resulted from the combined operations of elevation and denudation. It has been mainly by the unequal and irregular action of elevation, when applied to large areas, that the chief water-sheds of any country have been determined. But at the same time these elevations must have similarly affected the strata beneath the surface, and

* Mémoires de la Société Géologique de France, 2nd Ser. tom. II. p. 134.

have produced (where the superimposed Formations present a near conformability, and denudation is not excessive) a dip in the strata, corresponding in general inclination, although varying in its degree, with that of the surface of the ground above. Consequently, whether the rain falling on such a district be removed by the streams and rivers at the surface, or underground by absorption in some porous strata or by passing into the fissures or along the planes of stratification of others, still, in each case, the water would, when the above-mentioned conditions obtain, flow in the same general direction.

Now an examination of the map will show that, in the Tertiary and Cretaceous district around London, the course of the streams and rivers is, almost always, from the circumference of that area, towards the central valley of the Thames. In the same way, therefore, as that river and its tributaries thus effect the surface drainage of this district, would the circulation of water in the subterranean range of the lower cretaceous strata probably tend to take a generally corresponding direction; and consequently London appears to be as advantageously situated, with respect to these large bodies of underground water, as it is with reference to its fine and capacious river on the surface.

§ 14. *On the Thickness of the Chalk, and on the probable Depth beneath London of the Upper and Lower Greensands.*

123. These are points on which we are entirely without positive evidence, and can only hope to determine approximately by calculation on some geological data.

The thickness of the Tertiary strata, at a number of points in and around London, is well known; but that of the underlying chalk has not yet been proved. The greatest depth to which it has been here pierced is 300 feet.

The dimensions of the chalk in different parts of the south of England are very variable. Mr. Phillips estimated it at 820 feet thick at Dover; Mr. Greenough at about 1300 feet in the Isle of Wight; Mr. Conybeare as ranging between 600 to 1000 feet; Sir Henry De la Beche at 700 feet; and Dr. Fitton at 800 feet on the Sussex coast.*

If the stratification of the Tertiary strata were conformable† with that of the chalk, and we could ascertain the thickness of the latter at any one point, then we might expect to find it nearly the same in any district immediately adjacent. But although the want of conformability between these two formations is not very apparent, yet, when examined over a large extent of country, it evidently is not inconsiderable.

The chalk has been traversed at two places in Norfolk, —at Mildenhall, where it was found to be 250 feet thick, and at Diss, 510 feet—but in neither of these localities is it fully developed. The upper beds are wanting, and there are no Tertiary strata near by which to judge of the

* Fitton, Trans. Geol. Soc. 2nd Ser. Vol. IV. p. 318.

† Where the planes of bedding of the superimposed strata are parallel to each other they are said to be *conformable.*

probable position of its upper surface. At Saffron Walden, in Essex, we have, however, many of the conditions required. The town is situated on a hill at a distance of twelve miles from the outcrop of the Upper Greensand and Gault, and only a few miles beyond the boundary of the Tertiary strata. A well was there carried to a depth of 1000 feet entirely through the chalk. The bore had reached the chalk marl, and consequently it is probable that the Upper Greensand would have been found within less than 100 feet lower.

124. Now the Tertiary beds set in on the hills east of Manuden, eight miles to the south of Saffron Walden,* and on a level rather lower than the hill on which that town is situated. They are nearly horizontal, as also is the underlying chalk. This latter continues so nearly to Saffron Walden, that, I believe, a slightly increased height of the hill would have brought in the Tertiaries; 100 feet would probably more than have sufficed for this object. This would make the full thickness of the chalk in this district as much as from 1100 to 1200 feet. If no denudation of the chalk had taken place prior to the deposition of the Tertiary strata, its thickness at London might have been as great as this. But there is sufficient evidence to prove, that throughout the whole of the district to the south of Saffron Walden, the surface of the chalk was considerably denuded and worn down before the accumulation of the Lower Tertiaries upon it.

At various points along the highest summits of the North Downs in Surrey, there exist small and thin patches of the Tertiary strata *in situ*. Amongst them those on White Hill, Tupwood Hill, and Tandridge Hill near Godstone, on Denby

* I believe that the Tertiaries approach much nearer to Saffron Walden, on the hills near the south-east, but I have not been able there to obtain any good sections of them.

Hill near Dorking, and a few others, extend to the very edge of the chalk escarpment, overlooking the valley of the Weald. Therefore, as the Upper Greensand crops out on the slope of this same escarpment, the structure is one which admits of direct measurement of its different parts (Fig. 18).

The dip of the strata at the first three places is not more than 5° to 6° northward, and the slope of the escarpment is very steep. I selected these points, therefore, to make a rough calculation of the thickness of the chalk by observations with the aneroid barometer.* I had expected to find it in much diminished importance, but scarcely to the extent which the observations indicate. It would appear from them, that there are places in the range of hills above Godstone, where the entire mass of the chalk, taken from the base of the Tertiary strata to the top of the Upper Greensand, is less than 300 feet thick.

From these and other general observations I am also induced to believe that the thickness of the chalk along the

* The following are the measurements given by this instrument:—(the distance from 1 to 3 is about three miles)

	Thickness of the chalk. FEET.
1. Tandridge Hill	260
2. Tupwood Hill, immediately over the Godstone firestone quarries	234
3. Between White Hill and Plat Green Hill . . .	242

Some allowance must, however, be made for the dip of the strata in the distance, although short, between the edge of the Upper Greensand and that of the Tertiaries. At White Hill it may be necessary, on this account, to add 60 to 70 feet, probably not quite so much at Tupwood Hill, and about 100 feet at Tandridge Hill. White Hill was the only place which admitted of rough measurement by line; but even there the slope, although of difficult ascent, was not rapid enough to truncate the beds at right angles to the plane of stratification, as would be necessary for their exact measurement. From the outcrop of the Upper Greensand to within about 20 feet of the summit level, gave 380 feet; to this, 40 feet for a long gradual slope, have to be added,—together 420 feet. This measurement, being made at an angle several degrees removed from a right angle to the dip, is probably as much too great as that made by the barometer is too little, on account of the two points of observation not being sufficiently perpendicular one to the other. Allowing for the corrections necessary in each case, these calculations would nearly agree.

line of escarpment, between that part of it north of Seven Oaks and Reigate, does not exceed 300 to 400 feet. As it ranges westward it appears to expand gradually.

At Denby Hill, near Dorking, a well was sunk on the summit of the escarpment. It first traversed 26 feet of Tertiary strata; below this the work was continued through chalk with flints, and then for some way into the chalk without flints, to a depth of 370 feet. The chalk here dips more rapidly northward, and its thickness may probably be about 400 to 450 feet.

It must not be supposed that the chalk has had the Tertiaries spread over it subsequently to the elevation or tilting up of the North Downs, and that the unconformability is greater there than elsewhere; for there is abundant proof at various places along the boundary line of the Tertiary strata and the chalk, of the disturbance having affected the one formation equally with the other; both constantly having the same dip northward, which is frequently very rapid.

The most numerous sections of the chalk are exposed in pits on the slope of its escarpment, and again on a line bordering the Tertiary district. At these two points the dip of the beds is always at an angle varying from 5° to 60° northward. This agreement of the two extremes has led to the inference of a continuous rise of the chalk over the intermediate area, and consequently that its thickness within the Tertiary area must be very considerable. But we have shown at ¶ 118 and 119 that, although at its escarpment the dip is often rapid, the strata speedily resume a nearly horizontal position, and thence range in gentle undulations until by another flexure they disappear beneath the main body of the Tertiaries.* If, therefore, this form of structure be correct, and the expansion of the chalk between Godstone and Croydon be attribu-

* Over the broad belt of the chalk, outliers of Tertiary strata are dispersed at intervals, as at Headley-on-the-Hill, Walton, Worms Heath, &c.

table to the prolonged level of the same beds, rather than to the successive setting in of additional ones on its upper surface and the gradual thickening of the whole mass in its range towards London, then the same or nearly the same thickness might be maintained over all this area. The well sections tend to confirm this view, for the chalk marl seems to occur throughout this district at nearly the same level below the surface. At Wood farm, on the hills three miles north of Merstham, the chalk was traversed to a depth of 400 feet, when the chalk marl apparently was reached; and again at the same depth at Walton-on-the-Hill (which is partially capped by Tertiary strata). The same fact was noticed in the deep wells at the following places in this chalk district.*

	FEET.
Effingham, three miles westward of Leatherhead .	397
Cudham, between Bromley and Westerham† . .	394
Coulsden, between Croydon and Godstone‡ . .	400
Addington Lodge, near Croydon§ . . .	365
Ashurst Lodge, between Headley-on-the-Hill and Boxhill	397
Polsden, on the hills three miles northward from Dorking‖	509

125. The outliers of the Tertiary strata, in the midst of the chalk district, being, there can be little doubt, the remaining portions of beds originally continuous with the main mass of the Tertiaries, indicate that the elevation of the North Downs has taken place subsequently to the deposition of the lower beds, at all events, of these deposits. At the commencement of the Tertiary period, therefore, the surface of the chalk downs probably formed a nearly level plane from the summit of their escarpment in Surrey to the summit level of the hills in Hertfordshire and Cambridgeshire. Not that the Tertiaries

* These sections also show how deep the water level lies in these districts.

† The latter part of this well traversed chalk with iron pyrites (lower chalk).

‡ The last 100 feet through chalk without flints (lower chalk).

§ This stands on lower ground than the others.

‖ There is some reason to believe that this well and the one at Ashurst reach the upper greensand.

scooped out for themselves a trough such as that in which they now appear; but, that the chalk not having then been raised to its present elevation on either side of the Tertiary district, the surface of the hills beyond Croydon and Epsom, and that of those around Saffron Walden, formed a level surface continuous with that of the chalk now beneath London;* and originally the chalk may have been of nearly the same important thickness throughout this range of country, as it is at Saffron Walden.

The upper part of this formation having been usually distinguished by the presence of layers of flints, the occurrence of such layers, and the height of the hills, have caused the chalk around London to be referred to the upper chalk; and the thickness of the formation in the few places where it admits of measurement (as in the cliffs of the Isle of Wight, and of Dover, and Beachey Head partially), being very considerable, an impression has prevailed that its dimensions at London partake of somewhat similar magnitude. But in Suffolk and Norfolk the upper part of the chalk is, like the lower part, nearly destitute of flints. This portion of it I believe to have been denuded at London, and consequently that the thickness of the mass has been here much diminished.† This may have arisen from a greater relative

* The Eocene, or older Tertiary sea, extending, in fact, continuously over the whole of those districts.

† That there were great variations in the thickness of the chalk before the Tertiary strata were deposited upon it, is proved in the following instances of places, where, owing to the presence of Tertiary beds above, and of Greensands and older beds below, its actual total thickness in those districts of France has been clearly determined.

	FEET.		FEET.
Paris . . .	1394	Condé, near Valenciennes .	287
Calais . . .	762	Lille . . .	186

At Culver Cliff in the Isle of Wight, Dr. Fitton considers the distance between the Tertiary strata and the Upper Greensand to be about 1300 feet. Mr. Keele (May, 1850) informs me that at the Artesian well at Southampton they have now bored through 815 feet of chalk (here also overlaid by Tertiary strata) without having penetrated it.

elevation of the bed of the sea to the south, at the conclusion of the cretaceous period, in consequence of which the early Tertiary seas planed down its more exposed and elevated surface; and thus the upper beds of the chalk, which to the northward, owing to their greater depth from the surface, escaped this denudation, may have been removed by it in proportion as they trended southward. Hence there would result a gradual decrease in the thickness of the chalk as it ranges from north to south.*

126. We are thus furnished, presuming the rate of this variation to be tolerably regular, with the means of forming some estimate, which will probably be not far from the truth, of the thickness of the chalk beneath London. For if its thickness can be determined at any place to the northward, and again at one to the southward, of London, then the thickness of the chalk at any point on a line drawn between these places will probably be a mean, dependent upon the relative distance of that point from either extremity. Irregularities doubtlessly exist, for which, as they cannot be determined except by actual examination, some allowance must be made.

The probable thickness of the chalk at Saffron Walden, and at several places at the edge of the chalk escarpment in Surrey, has already been alluded to; it is necessary, however, to have a few more points on the north of London to guide our further inquiry.

Luton.—Near Ware, the river Lea is about 90 feet above Trinity high-water level at London, and at Hatfield about 230, being a rise of 140 feet in a distance of 9½ miles. From Hatfield to Luton the course of the river is about twelve miles, which, assuming the rise of the ground to continue nearly

* This unequal denudation may serve to explain some palæontological difficulties which exist respecting the synchronism of different parts of the Upper chalk; and at the same time those apparent anomalies will, I believe, be found to corroborate this hypothesis.

the same, would give 176 feet; consequently, Luton is probably about 380 to 400 feet above Trinity high-water mark. The hill at Zouches Farm, between Luton and Dunstable, is 830 feet above that level. The hills nearer to Luton appear rather lower, say 800 feet, and are capped thinly with Tertiary strata. This makes the height of the chalk, above the level of Luton, 400 to 450 feet, and as the well sunk in that town apparently reached the Upper Greensand at a depth of 475 feet, the total thickness of the chalk at Luton is probably about 900 feet.

The chalk escarpment above Wendover attains a height of nearly 900 feet above Trinity high-water mark, whilst the Upper Greensand crops out in the valley two to three miles to the north, at an elevation of about 400 feet. The difference arising from the dip of the beds, which is here very trifling, can hardly be more than 300 feet; and therefore the chalk at Wendover may be about 800 feet thick.

Again, Nettlebed Hill, between Henley-upon-Thames and Thame, is 800 feet above Trinity high-water mark. It is capped by 35 feet of Tertiary strata, and the Upper Greensand crops out at the foot of the chalk escarpment, a few miles to the north, and at an elevation of about 300 feet. Here, as at Wendover, the data are hardly sufficient—the thickness of the chalk may, however, possibly be about 700 to 800 feet.*

The table in p. 142 exhibits the conclusions which we may draw from these data.

The average of the last three numbers in that table, taken as a mean for London, gives exactly 600 feet. There appear,

* Mr. R. Mylne informs me that at Stanmore, near Watford, a well has been bored to the depth of 396 feet in the chalk, and that the lowest beds consist of the dark grey chalk marl. At Woolwich also the chalk has been penetrated to a depth of about 600 feet. In this latter direction I believe the chalk to increase in thickness.

therefore, to be reasonable grounds for supposing that the chalk under London is not more than from 600 to 650 feet thick.*

Names of places at the extremities of the lines.	Dist. from these extremities to the intermediate place.	Thickness of the chalk at the extremities.	Names of the intermediate place.	Probable thickness of the chalk at this intermediate point.
	MILES.	FEET.		FEET.
N. Nettlebed, Oxon	31	750	*Kingston*	600
S. Knockholt, Kent	20	450		
N. Wendover, Bucks	31	800	*Wimbledon Common*..	585
S. Titsey Hill, Limpsfield, Kent	14	450		
N. Luton, Beds	27	900	*Notting Hill, London* .	600
S. Tandridge Hill, Surrey....	18	380		
N. Saffron Walden, Herts....	39	1200	*Deptford*	590
S. Merstham, Surrey	15	350		
N. Saffron Walden..........	40	1200	*Stratford, Essex*	610
S. Tupwood Hill, Godstone. ..	13	300		

S. South of London. N. North of London.

Assuming this estimate to be correct, then the approximate depth to the Lower Greensand at or near London can easily be calculated. For if we take the Tertiary strata at an average thickness of 200 feet, the following measurements will probably be near to the truth :—

	Thickness.	Depth.
	FEET.	FEET.
Tertiaries	200	
Chalk	650	850
Upper Greensand	40	
Gault	150	1040

It therefore appears probable that the *Upper Greensand* might be reached at a depth of from 800 to 900 feet, and the *Lower Greensand* at a depth not exceeding 1000 to 1100 feet beneath London.

* Or as I have given rather extreme numbers in the third column, the probable thickness may be estimated at between 500 and 600 feet. The greatest depth to which the chalk has been pierced at London is 300 feet.

§ 15. *On the Height to which the Water from the Upper and Lower Greensands would probably rise at London.*

127. This point depends upon the elevation of the line of outcrop of the water-bearing strata above the level of the ground at London. As the general surface of the country rises gradually around London both to the north and south, and also, but less rapidly, to the west, the outcrops of the Lower Tertiaries, Upper Greensand, and Lower Greensand, which take place in those directions, are on levels necessarily higher.

If the outcropping surfaces of any of these deposits always kept the same level, and the flow of water in their underground mass were perfectly unimpeded, we could calculate exactly the height to which the water would rise above the ground at London in a tube driven through the intervening and overlying strata into the water-bearing beds beneath, —for it would be nearly to that of the outcrop of these beds themselves. But this exposed surface, far from presenting an uniform level, exhibits great irregularities; it forms a zone maintaining on the whole a considerable elevation above the Thames at London, but in which occasional depressions, caused by transverse valleys, occur.

128. The following list shows the approximate height of the surface in the different geological tracts, keeping as far as possible to the lowest levels of the country, and within the boundary of the effective area of the several deposits. They are taken chiefly from Bradshaw's "Maps of Canals and Rivers," and from the different railway levels. They are all reduced to the same standard; viz., that of Trinity high-water mark at London Bridge (note p. 38). These heights

may not always be quite correct, as several of the original ones were not taken on the exact geological spot required, and in those cases they are merely estimated.

Lower Tertiary Strata.

South of a line passing through London.	FEET.	North of a line passing through London:	FEET.
Deptford	0	Between Blackwall and Bow	0
Croydon	130	Hoddesdon, valley of the Lea	80
Carshalton	80?	Hertford, S. of	200?
Ewell	80?	Hatfield, S. of	240?
Epsom	110	Watford	170
Leatherhead	90	Uxbridge	100
Guildford*	96	Maidenhead, S. of	60

Upper Greensand.

Godstone, N. of	450?	Near Cambridge	30?
Merstham	360	Three miles N. of Hitchin	135
Betchworth, N. of	210	Near Dunstable	400?
Dorking, River Mole	110	Two miles N. of Tring	320?
Deer Leap, Wotton	270	Risborough, N. of	300?
Guildford, River Wey	100	Wallingford	140
Farnham	220?	Wantage	260
Burbage	440	Two miles E. of Calne	350?
Devizes	400		

Lower Greensand.

Maidstone, R. Medway	2	Cambridge, N.W. of	20?
River Darent, N. of Seven Oaks	220	Biggleswade	120
Westerham, Kent	280?	Woburn	350?
Oxted, near Godstone	360?	Leighton Buzzard	270
Merstham, S. of	250	Aylesbury, E. of	340
Reigate	270	Abingdon, E. of	160?†
Dorking	120		
Shiere	250		
Guildford, S. of	100		
Farnham	190		

In the two Greensands, the places are in regular succession from east to west.

* Further westward, and beyond the boundary of the effective area, the valley levels of the Lower Tertiaries attain the following heights:—Old Basing, 254 feet; Newbury, 236 feet; Sonning near Reading, 120 feet.

† The Lower Greensand, one mile west of Devizes, is at a height of only about 180 feet.

The relative average levels of the outcrop of the different water-bearing deposits are, therefore, as follows—

	South of London.	North of London.
	FEET.	FEET.
Lower Tertiary strata . .	84	113
Upper Greensand . .	284	242
Lower Greensand . .	204	210

129. The mean surface planes of the several formations, taken in the direction of their range and at their lowest levels in the several districts they traverse, form curves of considerable irregularity. This is owing, in great part, to their intersection at intervals by river courses, at which points the curves reach their lowest depression; while between them the country rises, and the curves attain their higher elevation. These breaks are frequent south of London, but on the north the curves are longer and less deeply indented.

With regard to the height at which water stands at the exposed outcrop of the several water-bearing deposits;—if it moved freely, and without impediment, through the strata, it would naturally fall speedily to the level where the outcrop was lowest. But the resistance caused by friction and capillary attraction so greatly retards the horizontal passage of the upper layers of the water, that, although necessarily always seeking to find its lowest level, it tends, owing to these causes, to accumulate above that level in the interior of the hills and rising grounds (see fig. 18). This continues until the water reaches such a height above the adjacent valleys, that the increasing pressure it exercises counterbalances the resisting forces, and then any further addition displaces an equal quantity of the water already accumulated, forcing it out as springs over the lowest marginal edges of the outcrop. Consequently, as the resistance depends upon the distance the water will have to travel and the lithological character of the strata, so, in proportion to the height and distance of any part of their surface above and from the lowest levels

of the same districts, will the water-line be placed on a higher level. Mr. Hopkins, of Cambridge, has suggested to me, that the resistance caused by the texture of the sands is of that nature, that the flow of water through them may, in fact, be compared to the flow of a viscid fluid whose cohesion varies according to the lithological character of the strata. On this view of the subject, the difference of level in the water-line at the outcrop of the strata will be more readily understood.

130. In the valley of the river Medway, at Maidstone, the water in the Lower Greensand stands at nearly about the level of Trinity high-water mark at London: but in continuing along the range of the exposed outcrop to the westward of Maidstone, the line of water level in the strata is found to rise to a certain extent with the general rise of the surface, attaining probably an elevation of about 240 or 250 feet. The transverse valley of the Darent again lowers this line to a point nearly coincident with the level of the valley—there about 220 feet above the Thames at London. Proceeding further westward, and keeping to the valleys, the following are the approximate highest and lowest levels at which the water stands in the Lower Greensand:—Westerham 220 feet, Merstham 200 feet, Reigate 250 feet, Dorking 120 feet, Shiere 230 feet, Guildford 100 feet, Farnham 180 feet; then crossing over to the zone of northern outcrop and proceeding eastward: Abingdon 130 feet, Leighton Buzzard 250 feet, Hincksworth, near Baldock, 120 feet, and at Cambridge the level of the water again descends to about that of Trinity high-water mark at London.

In the same way with the Upper Greensand the line of water level is about 250 feet high at Merstham, 200 feet at Betchworth, 100 feet at Dorking, 320 feet at Devizes, 120 feet at Wallingford, 330 feet at Tring, nearly 400 feet at Luton, and 120 feet to the north of Hitchin.*

* These numbers are only general.

131. This being the condition of the water in the strata at the surface, we have now to consider what the effect of this variable height of the line of water level will be on the water in those portions of them which pass underground beneath the Tertiary area. We know that the water in the Lower Greensand to the north of Seven Oaks stands permanently about 200 feet above the level which it has in the same deposit in the valley of the Medway, distant about twelve miles; that it rises to about 250 feet at Reigate, and only to 120 at Dorking. Again at Leighton the line of water-level is constantly maintained at about 250 feet above London, notwithstanding that the water can escape at Biggleswade at a level of 120 feet, and northward of Cambridge at about 20 feet.* But although the friction caused by the fineness of the sands impedes to such an extent the flow of the water as to prevent it from falling to the lowest levels of the outcrop, neutralizing in fact much of the lateral pressure—yet nevertheless the vertical pressure of the water, thus accumulated above the level of many of the surface-vents, must remain and exert a force on the mass of water in the subterranean strata, proportionate to the height of the water-level in the strata at their outcrop. For let us suppose that the water, which in the Lower Greensand at Maidstone and Cambridge is at about the level of London Trinity high-water-mark, stood also at the same height at Westerham, Reigate, Leighton, and in fact in all parts of its outcrop around London; it would follow, in such a case, that the pressure from all sides on the water in the central deep-seated

* The line of water-level in arenaceous formations at their outcrop slopes on the whole more rapidly than in the chalk—the water passing much more readily through the open fissures of this deposit than in the fine interstices of the sands. What, however, the one can accomplish by rapidity of transmission, is compensated for in the other by its thorough permeability and more sustained delivery. At great depths the water in the chalk finds fewer fissures for its transmission, whilst in the sands, with the same channels as in the superficial beds, it acquires far greater freedom of motion.

beds being perfectly equal, the water would everywhere tend to rise to the same uniform level as that of the outcrop. But as, on the contrary, there is superadded, to this equal common base, volumes of water, the sections of which form segments of circles, rising to a height of 220 feet at Westerham, 250 feet at Reigate, 120 feet at Dorking, 250 feet at Leighton, and 100 feet at Biggleswade, it is evident that they must exercise an additional pressure, in the ratio of their height, upon the water in the central deep-seated strata.

It will therefore follow that the water in the several portions of the outcrop of the water-bearing strata, which are at different elevations, must be considered as so many separate bodies of different height and variable pressure ; and consequently, if the superincumbent mass of impermeable strata be bored through at any place within the central area around London, the water would tend to rise to a height dependent upon the mean pressure of these several columns.

132. At London the water supply from the Lower Tertiary Sands is no longer in its normal condition, and therefore does not give correct data. The wells at Garrett and Waltham Abbey afford better, but still very limited, evidence, of the height to which the water from deep-seated water-bearing strata will rise. The surface of the ground at the former place is about 30 feet above Trinity high-water mark, and the general height of the outcrop of the Tertiary Sands, around Carshalton, is probably about 80 feet, being a difference of about 50 feet. The distance from the village to the line of outcrop is five miles. If we take the rise of the water, before the wells became so numerous, to have been about 25 feet above the surface,* then there will be a difference of 25 feet between the level to which the water rises from the Lower Sands and the level of these beds at their outcrop, or equal to a fall of

* I doubt whether it would be very much less even now in a fresh opened well.

5 feet per mile. At Waltham Abbey, allowing the rise of the water to have been 5 feet above the surface,—the distance to the outcrop of the sands being 5 miles, the height of the ground at that town about 55 feet, and at the outcrop, higher up the valley, 80 feet above the Thames, or a difference of 25 feet,—we have in this case for the same distance a difference of 20 feet, or a fall of about 4 feet per mile in the water-level.* (See § 4.)

The best point of comparison is, however, furnished by the well of Grenelle. The surface of the ground at this part of Paris is 102 feet above the level of the sea, and is distant about 100 miles from the outcrop of the water-supplying strata both to the eastward and westward of Paris. To the eastward, the height of the zone of outcrop appears to average about 400 feet above the level of the sea, or 298 above that of Paris, while westward it descends, between Rouen, Havre, and Caen, nearly to the level of the sea. Now the water at the well of Grenelle rises 120 feet above the surface of the ground; consequently the difference of the height to which it reaches and that of the outcrop east of Paris, is only 178 feet,† or equal to a fall in the water-level of less than 2 feet per mile.‡

133. But the delivery of water, when liberated by means of Artesian wells, depends not only upon the lithological character, but also on the volume of the strata; for it is evident, if a supply of 20 gallons of water per minute be

* The delivery of water at these wells is naturally very much less than those at Garrett.

† The Rev. Mr. Clutterbuck has observed that a line, drawn from the outcrop of the Lower Greensand at Lusigny to the sea, passes over Paris almost exactly at the height to which the Grenelle water rises above the surface, viz. 120 feet. These probably are mean points (see Appendix A).

‡ In the Artesian wells in the Tertiary strata at Paris the water only rises to within a few feet below the surface, or less than 150 feet of the height to which the water from the Greensands attains. At Anet, fourteen miles eastward of Paris, the water rises 23 feet above the ground, or 174 above the level of the sea.

obtained from a stratum 10 feet thick, that, were the thickness less (the texture remaining the same), in order to procure the same quantity in the same time, the water would have to flow with greater rapidity through its subterranean channels, to compensate for the diminution in their size; but this could only be accomplished by a greater drainage, and a more speedy exhaustion of the strata. Inversely, if the thickness of the water-bearing strata be increased, then also will the quantity of water, which they can transmit in a given time, be larger. Or, as more exactly expressed by Mr. Hopkins, "if we take a vertical section of two strata perpendicular to the course of the water flowing through them, then, if the velocity of the water in each case be the same, the quantity passing through them will be proportional to their areas." Now the Tertiary Sands do not average more than 20 feet in thickness, whereas the Lower Greensand may be taken at 200 feet.* A given section of these latter could therefore transmit 2000 gallons of water, in the time that only 200 passed through the former; but in fact not only are these strata thus much thicker, but they are also far more permeable. In this reasoning I am assuming, that the areas of outcrop are, *cæteris paribus*, in the same ratio as these areas of vertical sections. But although this is necessary to maintain a proportional supply, it does not follow that equal areas of outcrop will transmit equal underground supplies in strata of different thickness, for that would necessitate variable velocities, which, the other conditions being equal, could not exist.

134. Further, as the water can move freely in all directions through loose arenaceous strata, and as a cubic foot of sand will hold on an average 2 gallons of water, it follows that, in a deposit 200 feet thick, a cube of that depth will contain 8,000,000 gallons of water. Taking, however, only half that quantity, and supposing, which is really the case, that

* It is also apparently three to four times thicker than the same deposit in France.

as the water is delivered on one side, it is replaced on the other,—then a supply of 4,000,000 gallons would be effected by the body of water, contained in this mass of strata, flowing forward 200 feet. This quantity would be replaced by a fall in the water level of less than one inch over one square mile of the strata at their outcrop; or a fall of $\frac{1}{10}$th inch over the whole effective area (230 square miles) of the Lower Greensand would meet a delivery of 50,000,000 gallons in the central area at London. The movement, therefore, of the water through the mass of the strata, to effect so large a delivery even as this, would be so extremely slow, that, considering the gravity of the fluid, the friction would hardly have any influence;—the water would only acquire a perceptible velocity as it approached the points of discharge. The rapidity of the subterranean current would consequently be a measure between the extent of contributing surface, the thickness and depth of the strata on the one side, and the quantity of water abstracted and the size of the point of delivery on the other;—its motion would increase gradually from the surface downwards. The resistance attendant upon this acceleration is met by the increased hydrostatic pressure in the deep-seated strata, which at a depth of 1000 feet is such as to make perfectly easy, where a free escape is afforded to the water by means of Artesian wells, a delivery which, near the surface, the resistance of the sands would render impracticable.

135. With regard to the Upper Greensand, although it is of considerable thickness in Wiltshire and Berkshire, yet it diminishes in thickness as it approaches London; whilst at the same time the sands almost thin out, and the harder beds of sandstone alone remain. Therefore, the water would probably reach London principally through fissures in the rock, of which the dimensions and number are uncertain. If they should not be sufficiently capacious, then the flow of the water might be considerably obstructed, and the advantage

to be gained from the high level of its outcrop in a measure lost; otherwise they would form a convenient frame-work to receive the water collected and transmitted by the associated beds of sands, and would facilitate its delivery.

136. Taking all these considerations into account, and provided that no faults intervene to break entirely the continuity of the strata,* the probability is, that the waters, both from the Upper and Lower Greensands beneath London, would rise considerably above the surface of the ground, if set free by means of Artesian wells.

To determine approximately the height to which the water would ascend, it may be compared to the flow of a river of which the summit levels are formed by the margin of the outcropping strata, and its point of discharge placed on the opposite side at the part where the outcrop was lowest. But in the case of the Upper and Lower Greensands there is no definite single point we can fix on. I have therefore taken, as the base of a very general calculation, two points—the one the lowest in the northern zone of outcrop, and the other the lowest on the southern; the former in the neighbourhood of Cambridge, and the latter, of Maidstone. To each of these points I consider the water as flowing from the whole length respectively of each opposite zone of outcrop westward of these parallels:—or we may draw (second plan), according to the suggestion of Mr. Hopkins, as probably more correct in principle, lines from every point of the water-level along the outcrop, to points at the level of the sea along the coast. On either of these plans we have a series of inclined planes passing over the neighbourhood of London, and if we take the mean of them within that area, they may afford some measure of the height to which the water from the underground strata

* Or by fissuring the strata, to allow of an escape of water to the surface, which would lower the level to which the water would otherwise rise in the more central area. By such fissures also passing downward, the communication between disjointed strata might in some measure be kept up.

would probably rise above Trinity high-water-mark at London. I find the second mode of calculation gives results agreeing remarkably with the first. I annex them both.

Rise of Water.	1st Plan.	2d Plan.
From the Upper Greensand	about 130	136 feet.
„ Lower Greensand	„ 120	122 „

If, however, there should be any impediment to the underground flow of water in the Upper Greensand to the eastward of London, which is not improbable, then, as the point of lowest level at Maidstone would be shut out, the rise of the water from this formation might be considerably higher—as much probably as 150 to 160 feet above the level of the Thames.

Upon the height to which the jets were carried, would the quantity of water supplied by these strata be regulated.

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§ 16. *On the probable Quality of the Water in the deep-seated Beds of the Upper and Lower Greensands.**

137. Although this is a question on which it is not possible to speak with any certainty, yet, in the absence of direct evidence, there are some general indications afforded by the chemical composition of the several formations, and by the nature of the surface waters, which may assist us in a theoretical inquiry into the probable qualities of these subterranean waters.

It by no means necessarily follows that because the waters at the surface of any deposit are pure and good that they should prove to be so at great depths in the strata; neither can it be inferred that because they were indifferent at the surface, that they should continue defective in the deeper-

* For an account of the waters of the Lower Tertiary sands and the chalk, see Appendix C.

seated strata; for many of the chemical changes which take place at or near the surface, are brought about by agencies which cannot operate at great depths, where again other conditions of pressure and temperature produce results different from those which would obtain superficially.

In the case before us we shall endeavour to show, however, that the surface action is most likely to produce limited and local alterations, which do not extend far, or would be corrected, in the passage downwards of the water; and also, that if the water at the surface be good, it probably is not injured by its transmission underground.

Notwithstanding the solvent power of water generally, not only are limits placed to the extent of saline saturation, but also, for purposes equally wise, does this very power, by its universality,—whereby salts, of which a large number are incompatible, are brought together in the same fluid,—promote the decomposition and precipitation of a large proportion of the whole, and is productive, therefore, of a constant tendency to restore the water to a degree of purity fitting it for the uses of man.

138. The source of all fresh water is rain. It reaches the surface of the ground free, as a general rule, from all saline ingredients, but containing atmospheric air and a small quantity of carbonic acid gas.* Humboldt and Gay Lussac† have shown that the quantity thus held in solution equals about $\frac{1}{25}$th of the volume of the water, and that the proportion of the oxygen to the nitrogen, instead of being as 21 to 79, the proportions in atmospheric air, is as 31 to 69.

Now the rain on arriving at the surface comes into contact with the soil containing vegetable matter in a state of decay; the oxygen in the water tends therefore to unite with this organic matter, and to form carbonic acid gas, which remains

* And, according to Liebig, almost imperceptible traces of ammonia.

† "Mémoire sur les Moyens Eudiométriques," Journal de Physique, 1805.

dissolved in the water. If the water be retained long at the surface, or if the quantity of the vegetable matter be large, then the whole of the oxygen may be converted into carbonic acid; but if the water percolates through the surface soil more rapidly, then it carries into the substratum a portion of the air originally brought down by the rain; and that this air can be long held in the water, is shown by the fact of the water at the well of Grenelle, after passing 100 miles underground, and reaching a depth of 1800 feet, yet retaining 1·65 per cent. of air, in which the oxygen is to the nitrogen as 22 to 78.

Saussure has also shown that the surface of porous strata absorbs atmospheric air, taking up, however, the oxygen in much larger proportion than the nitrogen.* In passing rapidly into the extremely porous Lower Greensand, it is possible that the rain-water would frequently gain more oxygen from this source than it would lose by decomposition in contact with decaying vegetable matter in the vegetable mould.

The organic matter of the soil abstracts oxygen also from the atmosphere, and whatever may be the products at first formed, the ultimate ones always resolve themselves into carbonic acid gas. This, therefore, is the gas most largely and most generally absorbed by the surface waters, and, thus charged, they pass downwards into the body of the strata.†

139. We have now to consider the chemical condition of the strata themselves. It is shown elsewhere in this work (see Appendix D), that the nature and origin of the schistose

* The experiments of Prof. Schübler confirm this fact; the power of absorption being greatest in garden mould and least in siliceous sands,—clays and loams holding an intermediate place. The strata must be damp to produce this effect. Jour. Roy. Agric. Soc. Vol. 1. p. 177, 1840.

† The action of the ammonia is comparatively so restricted, and the formation of nitrates is so dependent upon local causes operating chiefly in towns, that the consideration of these two points is hardly necessary in this inquiry. For these and various other questions connected with this subject, see the Introduction to Liebig's "Treatise on Organic Chemistry," French Edit. 1840; and Dr. A. Smith "On the Air and Water of Towns."

and crystalline rocks, compared relatively with those of sedimentary origin, are such as to lead us to conclude, as a strong probability, that the changes, in which many of the latter deposits originated, have tended to remove a considerable number of causes of impurity in the waters of these derivative strata; and that from the very mode of accumulation of the Lower Greensand, the waters now percolating through it may probably not meet with many soluble salts.

This formation has every appearance of its having been derived from the debris of some of the older crystalline rocks. It consists essentially of quartzose sand, fine and coarse, all the grains of which are much worn and rounded. I have found in it mica in very small quantities, and rolled grains and water-worn fragments of felspathic minerals rather more abundantly.* The green grains of the double silicate of iron and alumina form occasionally separate beds, but are more frequently dispersed in the mass of the sands. Beds of clays occur in the central division, and, throughout, some of the sands are more or less slightly argillaceous. Carbonate of lime forms, in the lower division of this formation in East Kent, an important calcareous rock, which is but slightly developed in Surrey. In the upper division carbonate of lime is very rarely to be detected—it is almost entirely siliceous. The sulphate of barytes is found in small quantities embedded in the fuller's earth at Nutfield. Chert is common in parts of the Lower division, especially at Leith Hill. (See § 8.)

But that which characterises this formation and gives it a very marked aspect, is the extreme abundance of the oxide of iron. It occurs in almost all the strata, in the state of the hydrated peroxide, sometimes merely tinting them slightly, at other times colouring them red and ochreous;

* In the isolated mass of Lower Greensand at Faringdon, water-worn crystals of glassy felspar are very common. Austen, Journ. Geol. Soc. Vol. VI. p. 459.

whilst elsewhere it renders them deeply ferruginous,* and forms numerous thin bands of coarse iron-sandstone. Some of the ochres, which however are not common, may probably contain a mixture of the carbonate of the protoxide of iron, as all those examined by Berthier from the Lower Green-sand in France are composed of this mineral, with a lesser quantity of the hydrated peroxide.† Organic remains are very rare within the effective area of this formation around London.‡ In West Surrey they appear confined to the lowest clay beds, and in West Kent they do not ascend higher than the central division. Sulphuret of iron, and the sulphate of lime, are scarcely ever met with. In the neighbourhood of Westerham, some of the coarse sand beds of this formation have all the appearance of containing decomposed felspathic grains,—a white residue, insoluble in water and muriatic acid, being diffused through the strata.

140. Now, the surface waters on entering the mass of this deposit are, as before mentioned, probably charged with carbonic acid, oxygen, and nitrogen. The sands being almost entirely siliceous would not undergo any alteration ; but any dispersed fragments of felspar and mica, which consist of compound alkaline silicates, may be decomposed, although with extreme slowness, by the carbonic acid in the water, setting free soluble alkaline carbonates, and leaving as a residue insoluble silicates of alumina,—the basis of pure clay. The greatest proportion (almost all) of the iron in this formation being in the state of the hydrated peroxide, cannot be acted upon either by water or carbonic acid; but should it occur as a protoxide, then these agents would convert it into the carbonate—a mineral partially soluble in free carbonic acid ;—but if earthy or alkaline carbonates, or free oxygen,

* A large portion of the sands of the Upper division are nearly white, and are often very pure. † "Traité des Essais par la Voie sèche." Vol. II. p. 231.

‡ They are common, however, in East Kent, and in the Isle of Wight.

are, as generally happens, present in the water, this carbonate of iron would be immediately decomposed, and the iron thrown down as an insoluble hydrated peroxide.

The green grains of the silicate of iron and alumina are generally insoluble; but they are very variable in their composition, and although the specimen analysed by Dr. Turner contained only traces of potash, yet others analysed by Berthier on the continent, show that this alkali is sometimes present to the extent of 10 per cent. When this is the case they may be partially decomposed, and the iron taken up, which, however, the operation of the causes just alluded to would again precipitate.

141. *All* the simple salts of potash and soda, and most of those of lime and magnesia, are soluble, but the carbonates of the latter are not so, except in an excess of carbonic acid.

In the decomposition of the compound alkaline silicates, when the soda or potash are brought at first to the state of simple carbonates only, they cause the precipitation of any carbonate of lime present, by abstracting from it the free carbonic acid which held it in solution, and they themselves pass into bicarbonates. If the sulphate of lime be present, these alkaline bicarbonates would promote its decomposition. The freely soluble alkaline silicates may precipitate the carbonate of lime from its solution as a silicate of lime.*

In the course of these changes a very small quantity, both of iron and of silica, might be left in solution, but the quantity would be comparatively inappreciable. Traces of magnesia

* I am treating this question upon the ordinary laws of chemical affinity, which determine the action which one salt exercises upon another, and indicate which are incompatible. These are, however, the effects noticed under the ordinary pressure of the atmosphere, and with solutions comparatively strong; but there is reason to believe that in natural waters the extreme state of dilution in which the salts occur, pressure, and the mode in which they are set free, modify many of the changes which theoretically should ensue, and apparently render the presence of incompatible salts in the same menstruum, although only to a very limited extent, possible. This is, however, at present a point so little understood, that its value cannot be fixed; but yet it must be allowed for on the question of probabilities.

might also be occasionally disengaged by the decomposition of some of the felspathic minerals. The sulphate of barytes, which occurs in the Fuller's earth at Nutfield, is insoluble; it is besides very rare, and imbedded in clays. The presence of the chloride of sodium (common salt) would depend materially upon physical changes described in Appendix D. It does not exist in the water of the well of Grenelle.

142. The probabilities are, therefore, that water would, in its passage through the mass of the Lower Greensand, take up but very few mineral substances; that iron, which, from its extreme abundance most danger was to be apprehended, exists, with possibly only a few rare exceptions, as an insoluble peroxide; or if the presence of any organic matter, which however is of very unusual occurrence, should have reduced the peroxide, the resulting protoxide would be subject to decomposition by the causes described above.

I am aware of the danger of reasoning upon large masses of strata, with only comparatively small superficial portions of which we are acquainted; but still, as the deposit is one which has been accumulated under water, with materials of a common origin spread over considerable areas, it is not probable that the strata underground differ materially from those portions of it at the surface, to which our knowledge extends. The geological data indicate the probable physical operations which accompanied their formation, and these again point to the chemical reactions which were most likely to have been brought into play during those changes. I think, therefore, there are fair grounds whereon to argue the general probabilities of this question.

143. It now remains to consider *the actual quality* of the water obtained in wells, springs, and by drainage, on the surface of the Lower Greensand,—a point on which the evidence is very scanty.

In the communication made last summer to the Institute

of British Architects, I was unable to give an opinion on the probability whether or not the water from the deep-seated beds of this formation beneath London might be found fitted for domestic purposes. I had at that time visited only a few localities in the Lower Greensand districts, and although many of the waters appeared to be very good and pure, yet having been informed that some of the well waters were hard, and seeing the extremely ferruginous appearance of parts of the district, I felt it necessary, until I could account for the one, and know more of the mineral condition of the other, to consider the question as doubtful. But further observations have satisfied me that the impure condition occasionally of the water arises from local causes, and that, apart from these, the quality of the water is generally good.

144. I believe, however, that neither well water, nor superficial springs, can be taken as fair tests of the quality of the water at great depths below the surface. In the first place, owing to the necessity of having ordinary wells open at top and loosely bricked round the sides, organic matter is liable to be conveyed into them by percolation of the immediate surface water, or by other causes,—as the growth of some of the lower classes of plants. The decay of such substances decomposes the air contained in the water, and generates carbonic acid.* The consequence is, that well waters

* I need scarcely point out in confirmation of this view how common an occurrence carbonic acid gas (foul air) is in wells, or the accidents to which it gives rise. One of the well waters analysed by M. Maumené gave per 1000 litres,—nitrogen 18·35 litres, carbonic acid 48·42, and no oxygen ; while in an adjacent river there were found nitrogen 18·68, oxygen 8·22, and carbonic acid 4·15, (Comptes Rendus, Aug. 1850). M. Deville's analyses give corroborating results (Ann. de Chim. et Phys. t. XXIII. p. 32).

Mr. West mentions some general experiments proving the same leading fact (Journ. Roy. Inst. Vol. I. p. 45, 1830-1) ; and he afterwards further showed that whereas a gallon of the water of the Thames at Kingston, contained 2 cubic inches of carbonic acid, and 6 cubic inches of nitrogen and oxygen, the water of the Chadwell spring (Ware) contained 10·5 cubic inches of the former, and 7 of the latter gases ; while in the water of the Treasury pump they were in the proportion of 15 to 7·5 cubic inches. (Report on the Water Supply, 1834, p. 49).

usually contain much larger quantities of free carbonic acid than any other ordinary description of water, and all free oxygen tends gradually to disappear. When this takes place in the Lower Greensand, the remaining vegetable matter in the water probably slowly abstracts the oxygen it requires, for its conversion into carbonic acid, from the peroxide of iron present in the surrounding sands, forming then, with the protoxide, a carbonate slightly soluble in free carbonic acid. The like cause will lead to an additional quantity of carbonate of lime, if any be present in the adjacent strata or in the brick work of the well, being taken up. These effects, however, appear very variable. Where the well is in constant use, and the draught of water rapid, it is little affected by these causes; but when it is allowed to stagnate, or it is not much used, they inevitably exercise an injurious influence.

The air, therefore, which the rain absorbs from the atmosphere, appears to act a most important part in maintaining the purity of the surface waters. It supplies oxygen to bodies, whose affinity for that element is such, that, if none existed uncombined, they would abstract it from those substances which yield it most readily, and thereby give rise to a number of decompositions, the result of which would generally be to produce some more soluble compounds. Among its other properties it precipitates the protoxide of iron from its salts in solution as an insoluble peroxide,—decomposes the hydrosulphurets,—and consumes all organic matter.

145. It is probable that the ferruginous waters, occasionally met with on the surface of the Lower Greensand, often originate in a double decomposition, which takes place after the water issues from the strata. The effect is always most apparent where the discharge of water is scanty and slow, and the ground low and marshy. The action which takes place is generally the same, only stronger, as that above alluded to in wells but little used, the soluble carbonate of iron being

formed at the expense of the peroxide by the action of organic matter. In marshy grounds, however, the iron is frequently taken up by a vegetable acid.

146. When the water issues immediately at the junction of the Lower Greensand with the Gault, a different change sometimes takes place. Both carbonate of lime and iron pyrites occur occasionally in this position, and, under certain conditions, the latter passes, by absorbing oxygen from the air in the water, into the soluble sulphate of the protoxide of iron: this being again decomposed, by exposure, into a soluble sub-salt of the peroxide and an insoluble hydrated peroxide; whilst a proportion of sulphuric acid is set free and combines with any earth* or alkali present,—forming salts all more or less soluble.

This change, however, is of unusual occurrence, even at the boundary line with the Gault, whilst in the large underlying mass of the Lower Greensand, iron pyrites is so rare a mineral that I have never observed this phenomenon within the proper area of that formation.†

* Generally lime—sometimes alumina and magnesia.

† I have noticed this decomposition in places where it is apparently owing to the presence of fossil shells mineralised into iron pyrites. A very curious case in point, arising apparently from this cause, occurs, in the Tertiary series, in the thin beds of green sand belonging to the middle division of the Bagshot sands. In this bed pyritical casts of *Turritella*, *Cardium*, *Venericardia*, &c. are found at Goldsworthy, near Woking, and at some places near Chobham, on the hill slopes around which village this central division crops out. They are found also at Winchfield. I have never been able to preserve any of these fossils in a perfect state. They always effloresce after exposure for a time to the air, and become covered with small crystals of sulphate of iron. A similar change probably takes place very slowly, and naturally, in the strata themselves at their exposed surfaces; for, as they are permeable, the aerated water which passes into them, furnishes oxygen to this sulphuret of iron, and converts it into a soluble sulphate, which is taken up by the water that oozes out at the junction of this sand with the bed of clay upon which it reposes. A further quantity of oxygen effects a further decomposition, precipitates the iron, and produces earthy and alkaline sulphates. A small quantity of oxide of iron, combined probably with a vegetable acid, remains however in solution. The recent analyses by Prof. Brande and Mr. Warington, of the waters of some of the small streams of this district, in Mr. Rennie's "Report on the Supply of Water to be obtained from the Bagshot district," show that they are frequently slightly chalybeate, containing

So long as the hydrated peroxide of iron is in presence of water holding only air and carbonic acid in solution, no change takes place; so that the surface of the Lower Greensand, although frequently so highly ferruginous, remains unaltered after long exposure to the atmosphere, unless some preliminary deoxidizing process, under certain favourable conditions, comes into operation.*

I believe, therefore, that the occasional hardness of the well waters, and the ferruginous character of some pools and springs on the exposed outcrop of the Lower Greensand, result generally from purely local causes, whose action does not extend beyond the surface.

147. But when the water issues more abundantly, and flows

carbonate of lime, chloride of sodium, sulphate of soda, carbonate of soda, silica, oxide of iron and organic matter, in quantities, taking the whole together, of from 10 to 12 grains to the gallon. As this green sand is composed in a great measure of grains of a dark green silicate of iron, some slight decomposition of that mineral may perhaps also supply some of the iron, for in the analyses of Prof. Brande and Mr. Warington, a small quantity of silica is shown to be generally held in solution.

I mention this case as a peculiar geological fact, and to observe that this chalybeate condition of the water is a phenomenon of local occurrence, and by no means dependent on any general conditions of the Bagshot sands. The chalybeate springs are small, and occur at intervals along the zone of outcrop of these green sands. The thick and more important mass (100 to 150 feet) of yellow, ochreous, and whitish sands forming the upper division of the Bagshot series, and overlying this thin bed of green sand (6 to 15 feet thick), usually transmits water in a state of great purity.

The waters, therefore, of the two districts must not be confounded together. The upper sands, which contain only the hydrated peroxide of iron, with traces probably of the protoxide, are comparatively unalterable by rain water, but in the lower levels, where the green sands and foliated clays crop out, then the waters, which are stopped and thrown out by these latter beds, are liable to be affected by the abovementioned causes. Again, in the lower sands (120 feet thick) of this series,—when, as at Cobham, Claremont, and Esher, the central division does not cover them,—the springs are of remarkable purity. The relative districts occupied by the Upper and Lower Bagshot series, are defined on the Map. The central beds form a band, usually very narrow, at the junction of the two, but around Goldsworthy Hill and Chobham they are spread over a larger surface. I have not however been able to trace them between Ash and the western side of Hungary Hill, near Farnham, where they appear to be either wanting, or else are in much diminished force.

* In ordinary vegetable decomposition the oxygen is supplied by the atmosphere: it is only when air has not free access, that the more fixed combinations of oxygen are attacked.

freely, or when the wells are old, and in constant use, then a better criterion is furnished of its probable quality at greater depths. In this case, however, care must be taken not to form too favourable a conclusion; for on reference to fig. 18, p. 94, it will be seen that the rain water is constantly passing through that portion of the strata included between the surface and the line of water-level s, s', x, s'', which consequently must in the course of ages become thoroughly cleansed of all the more readily soluble salts, and must present, when the formation consists mainly of quartzose sands, as in the case of the Lower Greensand, a large mass of strata constituting a most perfect natural and well-washed filter. Below this line the water remains stored in the strata, and its quality will depend upon the conditions, elsewhere inquired into, relating to the drainage which the strata have undergone since their formation, and the rapidity of the present underground current, which in any case must be exceedingly slow* (see Appendix D).

The superficial decompositions may therefore be almost always referred to atmospherical agencies inoperative beyond the immediate surface; whilst large and perennial springs are alike uninfluenced by these processes, and unaffected by any change which the chemical nature of the formations may yet operate in the water in the strata more deeply seated than those through which their course lies. But, as water may have been slowly permeating through these deep-seated strata for a very great length of geological time, it might now possibly be found to be, in these subterranean reservoirs, as pure, or nearly so, as that which traverses the strata for a shorter space at their outcrop only. It is, therefore, possible that the quality of the spring and underground waters may

* It is well known that water from Artesian wells in strata of sand frequently become much purer after two or three years use. The more soluble salts are first washed out. (See p. 218).

assimilate, and that the determination of the condition of the former at the surface of the Lower Greensand may be admitted as evidence of the possible general character of the water in the interior of this formation;—the difference which may exist between them being chiefly one of degree.

148. From general observation merely, I am led to infer that the quality of the spring and well water in the Lower Greensand districts is much above the average purity of such waters ordinarily. From inquiries I made in the districts between Biggleswade, the beautiful village of Old Warden, Shefford, Silsoe, Clophill, Woburn,* Brickhill, and Leighton Buzzard, the water would appear to be, with very few exceptions,† everywhere excellent for all domestic purposes: it seems almost always to be extremely clear and limpid, and in no instance did I observe that it had taken up any of the iron so abundant in the ferruginous sandstones of this district. In fact, speaking merely from the general indications, and sight, and taste, I hardly know a district, formed of secondary rocks, in which generally the water appears so pure and good in every respect.

Passing to the districts south of London:—some very large and fine springs of excellent water issue from the base of the Lower Greensand near Weston Street, between Guildford and Dorking.

Dorking is almost entirely supplied by springs in the upper part of the Lower Greensand. The water is said to be good, and the supply unfailing. In the wells at Betchworth, Reigate, Bletchingly, and Westerham, the water does not appear

* I have since received further information from Leighton more particularly confirming this opinion. Even the ordinary well water there appears to be good, and softer than usual. The supply is abundant.

† A portion of the district is covered by the "Boulder clay drift," which contains a large proportion of debris of calcareous rocks, and of impure shales. Where wells are sunk through this superficial deposit, the water may frequently be injured by it.

to be generally so pure as in some of the other districts; still it is considered good, except when deteriorated by want of sufficiently quick use.

The water in the well sunk through the Gault into the Lower Greensand at Merstham is hard, but that arises apparently from the causes before mentioned, and also possibly by its being slightly injured by the gault, in the clays of which the shaft is sunk.

The water of the fine springs at Riverhead, near Seven Oaks, appears to be very good but not very soft. They issue near where the calcareous beds of the Lower Greensand crop out, and probably on that account contain more carbonate of lime than usual in the waters of this formation.

149. In the absence of exact analyses I annex a list of the hardness of a few of these waters (in the chief tracts of outcrop to the north and south of London), according to Dr. Clark's test, as it is a scale to which of late very general reference has been made.* Mr. Warington, who has had

* According to Dr. Clark—"Each degree of hardness indicates as much hardness as would be produced by one grain of chalk per gallon, held in solution in the form of bicarbonate of lime, free from any excess of carbonic acid. The degree of hardness caused by a lime salt depends, not on the state of combination of the calcium it contains, but on the quantity of the calcium." "A quantity of a soluble magnesian salt, equivalent to one grain of chalk, destroys a like quantity of soap test, and consequently indicates one degree of hardness. The same is the case with the salts of iron, and salts of alumina. Salts of the alkalies do not produce hardness." ("Note on the examination of Water for Towns," 1847, to which I beg to refer for fuller information.)

Opinions with regard to the merit of this test are very conflicting. If the value of a water supply be considered to depend generally upon these essentials;—1, its dietetic qualities,—2, its detergent properties,—3, the amount of solid residue left by evaporation, then with reference to "2" and as showing the *actual* hardness of a water *from whatever causes it may arise*, with regard simply to its *detergent* properties, and as a comparative reference on this particular point with other waters, this test is practical and convenient. (Objections have, however, been made to its accuracy even as a comparative test, on account of the difficulty of obtaining a solution of uniform strength. It evidently requires much care.) But with regard to "1" and "3" it does not appear to me to be at all admissible. The numerous and variable reactions and modifications caused by the presence of the many inorganic and organic substances, can, with reference to these important points, be discriminated and explained by chemical analysis alone.

considerable experience in the use of this test, has had the kindness to perform these experiments for me. They show an average hardness of 9·57°.

Source, and name of the place whence the water was obtained.	Division of the Lower Greensand.	Degree of hardness.
Spring, Riverhead*	Lower.	13·1°
„ Dorking†	Upper.	12·8
„ „	„	10·4
„ Weston Street	Lower.	8·5
Well, Leighton-Buzzard	Upper.	9·6
„ „ Heath	„	3·0

150. With regard to our knowledge of the actual quality of the Lower Greensand water at depths beneath the surface we have but very few facts (and those are not of exact analysis), relating only to two localities, and both of those only at short distances from the outcrop of the strata. The Rev. J. C. Clutterbuck informs me that in an Artesian well at Hincksworth, near Baldock, traversing the Gault, and ending in the Lower Greensand, the water is "particularly soft, clear, and of good flavour." He afterwards adds, "the only point which requires attention appears to be that if not used as quickly as under ordinary circumstances it becomes a little cloudy."‡ I believe that these observations may be applied generally to the water procured in the same way and from the same source at and around Cambridge, where such wells are numerous, but to this I cannot speak positively.§

* In a shallow well in this formation, near Abingdon, which however is of too recent construction to give a fair result, Mr. Warington found 15·4 of hardness. This he suspects arises in some measure from the presence of magnesia.

† I am informed that some of the springs in the town are probably affected by the absorbent system of drainage practised there.

‡ It is to be observed that the water stands in a shaft in the upper part of the well.

§ Since writing the above, Mr. I. Deck has obliged me with more particular information on this point. As the facts are interesting, and have a general bearing upon the whole question, I annex his statement as received (18th Jan. 1851).

"The water derived from boring to the Lower Greensand varies in its component

151. *Upper Greensand.*—This formation presents a mineral character of so much uniformity over its whole area, that its waters probably will not be found to vary very materially. They are usually hard. I am not aware that any analysis of them has been made. The district being small, compared to that of the Lower Greensand, there are far fewer opportunities of judging of the quality of the waters either by springs or wells.

A very good spring, much resorted to formerly, flowed just below the church at Merstham.* Between Gatton and Dorking there are several wells sunk at the foot of the chalk downs into the Upper Greensand, at the base of which, in a stratum of sand sometimes green, and other times light coloured, and immediately overlying the gault, the spring is found. The water is said to be good. A very fine spring issues, apparently from the same stratum, at Shiere, between Dorking and Guildford.

In these cases the water seems to pass through the lowest

parts in different parts of the town. In some places it is highly impregnated with iron, so as to render it unfit for culinary purposes, and likewise with vegetable matter. The first supply is generally impure, but after a period, varying from two months to as many years, it gradually becomes more pure, and in some instances no trace is left of ferruginous or vegetable impregnation.

"It is what is denominated *hard* water, containing carbonate and sulphate of lime, the solid contents of 1 gallon varies from 14 to 20 grains."

It must be observed that, as the water does not rise to the surface, the shafts of the wells at Cambridge are necessarily sunk into the gravel and gault, and the water is therefore liable to the changes described in a previous part of this chapter. (¶144).

Mr. Deck afterwards informed me, that, "In a well recently bored 134 feet deep in Bridge Street, the water was excellent;" that "in Russell Street a bore recently made 137 feet deep, yields a remarkably soft excellent water." He states that "no town is better situated for a supply of water," and that he is "not aware of the river water being used on any premises in the town, the water from the bores being preferred."

According to Mr. Warington, two specimens of the Cambridge waters just sent me by Mr. Deck, indicate the following degrees of hardness:—

Well in Bridge Street bored in 1850 . .	8·8°
Another well bored in 1812. . . .	11·0

Re-agents failed to detect in either of these waters the slightest trace of iron.—(For further particulars of the Cambridge wells, see notes, pp. 183 and 192.)

* The cuttings for the railway have now diverted it.

beds, and is only moderately hard, less so than springs in a chalk district. In the middle and upper beds, on the contrary, the water appears fully as hard as the surface chalk waters. The supply of water at Devizes is from wells 60 to 90 feet in this formation. Outside the town the water is tolerably good, but in the town the defective state of the sewerage has, owing to the very porous nature of the strata, led frequently to the infiltration of so much organic matter into the wells as materially to injure the water.*

Again, in a tract extending from Wantage to near Watlington, the Upper Greensand furnishes a rather hard water. Further eastward the zone of outcrop becomes so narrow that there are few opportunities of judging of its springs. It has been sunk into, in places at a short distance from its outcrop, and found fully charged with water; as near Tring, at the level of about 350 feet above the Thames, and again at Luton at about 400 feet above that level. At this place I am told that this deposit was 475 feet below the surface, and that water of a very good quality rose with great force and abundance to within 16 feet from the top of the shaft: the distance from the outcrop is $8\frac{1}{2}$ miles.

The following list shows the hardness of the waters, in the three principal tracts, as determined by Mr. Warington.

Source and name of place.	Degree of hardness.
Spring at Shiere........	11·0°
" near Devizes	20·0
" " Abingdon..............	23·0

Average hardness 18°.

152. But we know in the case of the chalk (see Appendix C), that its waters, which at the outcrop are hard, are soft and alkaline beneath London; it is uncertain, however, whether this does not arise in great part from the infiltration of water

* This is in course of being remedied: the same at Dorking. In the mean time these waters afford no fair criterion of the general quality of the water in those districts.

from the overlying Tertiary sands. It therefore forms no criterion of the changes which might take place in the subterranean waters of the Upper Greensand, some of the beds of which deposit assimilate very closely to those of the lower chalk in chemical composition. It is not improbable that much of the carbonate of lime might be precipitated by alkaline salts, the presence of which (as soluble silicates) in this formation is more than probable.*

But we can in some measure judge by analogy, for its water-bearing beds bear a much closer resemblance in lithological character, than those of the Lower Greensand of Surrey and Bedfordshire, to the strata supplying the well of Grenelle. In the neighbourhood of St. Dizier and Troyes, calcareous Greensands, very similar in appearance (but with more of the green grains) to those of Devizes and Wantage, prevail: the siliceous is generally mixed with calcareous sand, which latter frequently forms a cement consolidating it into a soft calcareous sandstone. The water traverses these beds, and issues at the well of Grenelle, in a state of *remarkable purity* and containing but a very small quantity of carbonate of lime. The bicarbonate of potash, which is present, may have had some influence in this result (see Appendix A).

In this country the Upper Greensand consists essentially of a calcareous base, occasionally much mixed with clay, and containing the dark olive green grains of the compound silicate of iron, either irregularly dispersed throughout the strata, or sometimes forming separate beds.

As before mentioned, Dr. Turner found no alkaline base in these grains.† It was in those from the Upper Greensand at Havre ‡ that Berthier detected 10 per cent of potash. In

* May not the unusually large produce of the wheat crops in the district formed by the bare outcrop of this formation, in parts of Berkshire, possibly be owing partially to the presence of decomposable alkaline silicates, as well as of phosphates?

† They were from the Lower Greensand.

‡ And Wissant.

Germany a somewhat different result was obtained, but still there was an alkali in combination. This substance is evidently a mineral of variable composition, and with isomorphous bases, and must consequently differ materially in its resisting power to the action of the air, or of aerated water.* If potash or soda be not present, then it is probably unalterable; but if it contains any alkaline base, it will be apt to decompose (although not at all readily), and liberate a carbonate of potash or soda and the protoxide of iron, which latter speedily passes into the peroxide, and is precipitated as an ochreous deposit. In this country, however, these green sands remain almost invariably unchanged from exposure to the atmosphere.†

With the exception of this silicate, the salts of iron are almost as scarce in this formation as in the chalk. Phosphate of lime occurs at some places in considerable abundance, in the form of dispersed concretionary nodular masses. This mineral is sparingly soluble in water, charged with carbonic acid, and traces of it therefore would probably be left.

Some combination of chlorine (probably the chloride of sodium) has, I am informed, been detected in the Upper Greensand at Devizes. Iron pyrites is found in this formation in East Kent, but elsewhere it is not a common mineral. Vegetable and organic matter also of very limited occurrence.

153. With regard to surface impurities affecting the waters in either of the Greensand formations. Admitting that there existed superficially, in some localities, strong earthy or mineral impregnation of the water, and of such a description as to be transmitted to the mass of the more deeply-seated waters. Issuing again as springs in the vicinity of the strata causing

* I believe that these green grains are probably derived from some variety of Hornblende or Augite,—minerals common in many of the rocks of igneous origin. (See Appendix D.)

† These observations apply also to the green grains of the Lower Greensand, where however they occur more rarely.

the impurity, these waters might be unfit for use; but if they descend lower, and have to traverse several miles of underground strata, they would become mixed with such large volumes of water, derived from other portions of the outcropping strata, that the state of extreme dilution would probably render them innocuous; or else, if free oxygen and carbonic acid, or alkaline salts, existed in the other waters with which they thus became blended, the objectionable salts would be liable to be decomposed, and insoluble residues formed by these reagents.

Altogether, judging from the general mineralogical character and surface-waters of the Upper and Lower Greensands, and from analogy with reference to the well of Grenelle, I am led to conclude that the quality of the water in those formations, as they exist beneath London, would probably be found to be good, and might even be extremely pure.* With regard to their temperature, if we take the mean for the surface at 50°, and the increase for the depth in the ratio of about 1° Fahr. for every 50 to 60 feet, then the water from the Upper Greensand, would have a temperature of about 63° to 65°, and that from the Lower Greensand of 66° to 70° Fahr.

These views are necessarily hypothetical: I submit them merely as a question of probabilities, the value of which will depend on the correctness of the geological and chemical data upon which they are founded. To draw more exact inferences it would be most desirable to institute a series of quantitative analyses of a number of the surface spring waters. In the absence, however, of direct evidence, which can be supplied only by an Artesian well itself, the subject is one which, even in its present state, admits, I conceive, to a certain extent, of inductive reasoning; although from the large dimensions and complicated nature of the masses of strata under inquiry,

* The character of these two waters would, however, no doubt differ; of this, possibly, some advantage might be taken.

the discussion must unavoidably be confined to the broader considerations, and can but faintly indicate the possibility of certain general results.

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154. In the foregoing remarks the question has been treated entirely upon chemical grounds, but the curious results of the experiments recently made by Mr. J. T. Way,* tend to show that there is some inherent power in the apparently merely mechanical action of common clay, present in the surface soil or contained in the undisturbed strata, which causes it to absorb many of the salts held in solution by water. If this be the case, it cannot fail to have a most important bearing upon the condition of the subterranean waters.

Although the inquiry is at present too novel and uncertain to form the ground of any very definite positions, yet the conclusions of Mr. Way are so marked and distinct that they must certainly be taken into consideration in a question of this description.

The absorbent power is apparently independent of chemical forces, although it cannot resist any strong exhibition of them. All that was previously known on the subject was confined to a few experiments of Berzelius and others, who had shown that even the first portions of sea-water filtered through sand (probably mixed with some clay) came out fresh. Mr. Way has now ascertained that potash, soda, ammonia, magnesia, and their carbonates, can, to a certain extent, be separated from water holding them in solution, and rendered insoluble, by filtration through clay. But the action on all the other salts of these alkalies is different;—they

* Journ. Roy. Agricul. Soc. Vol. XI. p. 313, 1850. See also the interesting Observations on the oxidising power of Siliceous Sands, and their powerful action in purifying water by filtration, in Dr. A. Smith's paper "On the Air and Water of Towns," Trans. Brit. Assoc. for 1848, p. 16.

are decomposed, the base only is absorbed, and the acid unites with any lime present in the soil. The action is not so strong on caustic lime and carbonate of lime, but still it exists; none, however, takes place upon the other salts of lime. This absorbent power of clays seems to vary generally from a $\frac{1}{4}$ to 2 per cent, although occasionally it is as much as 4 per cent, on the mass.

Now it is evident that the effect of this power acting on waters traversing strata of loose siliceous sands, mixed sometimes with clays, is likely to assist most materially the ordinary chemical action, in purifying these waters from a portion of their saline ingredients. When it is considered that the waters have to pass through many miles of the Lower Greensand, in some places entirely siliceous, and at other places partially argillaceous, it really becomes a question whether the water may not be, to a very great extent, freed from extraneous matter, and rendered by this means only, so far as regards the alkaline and earthy salts, comparatively soft and pure. This property, combined with the action of chemical affinities in promoting more especially the precipitation of metallic bases, and with that of siliceous sands in oxidising and dispersing organic matter, would appear to be part of a great natural law, holding in balance and counteracting the injurious effects which might otherwise follow from one of the most valuable properties of water—its solvent power.

Since the above pages were written, the valuable Appendices to the "Report on the Supply of Water to the Metropolis," by the General Board of Health, have been published. Dr. A. Smith shows, that the surface-waters (ponds and springs), of part of the Lower Greensand district in the neighbourhood of Farnham, are very pure and good, containing upon an average about six to seven grains of inorganic matter per gallon, and varying in hardness from about $2\frac{1}{4}°$ to $9°$. Prof. Way bears testimony to the same fact, and gives a further development of the interesting views alluded to above. Appendix No. III., pp. 99 to 142.

VI. CONCLUDING REMARKS.

155. We have shown in the preceding pages, on the evidence of geological structure, the probability that the *Lower Greensand* of the hills of Kent and Surrey, of Oxfordshire, Buckinghamshire, Bedfordshire, and Cambridgeshire, could, through its subterranean strata, contribute largely to the water-supply of the metropolis; and that in addition to these districts we may, in the case of the *Upper Greensand*, look also to the downs and valleys of parts of Wiltshire and Berkshire as another source of supply. We have now to consider whether the general conclusions to which we have arrived are confirmed by comparison with results which have been obtained elsewhere; and whether the objections which have been made to the use of Artesian wells, on account of expense of construction,* insufficiency of supply, defective quality of the water, and want of permanence in the springs, are valid against the system generally, or hold good only in particular cases.

156. The grounds of objection are on the whole apparently conclusive with respect to the *Chalk* and the *Lower Tertiaries*, the supplies from which, though of considerable value, are limited and insufficient to meet the wants of a city of the

* On the question of cost I can only speak generally; as it, however, forms one of the grounds of objection against the use of Artesian wells, I have collected a few facts bearing upon this point, which will be found in Appendix E. From them it would appear that the Upper and Lower Greensands beneath London might be reached by boring at an expense less than that which has been frequently incurred in sinking deep wells merely into the chalk. As the water would almost certainly rise above the surface, tubular bores alone would be required, and the expense of shafts and pumping avoided.

The labour and expense of obtaining water from these sources would also only be proportionate to the quantity supplied; each well being perfect in itself, and requiring no general preliminary works.

magnitude of London, arising in one case from unsuitable lithological character, and in the other from restricted superficial development of the permeable strata. But I conceive that they are not applicable to those great masses of permeable strata—the Upper and Lower Greensands—which exist at greater depths beneath, and crop out at greater distances from, the Metropolis; for these formations occupy superficial areas extensive enough to receive, and are of dimensions adequate to transmit, a volume of water which, if not sufficient, would probably at least contribute a very important proportion towards the quantity required for the water supply of London.

157. I am further led to conclude, after a careful examination of the geology of the country extending from Wiltshire to the coasts of Kent and Norfolk, that there probably is no large city in Europe the situation of which is so peculiarly favourable as that of London, for obtaining, by means of Artesian wells, an abundant supply of water of a quality, which, there are reasonable grounds to believe, would prove pure and good. The position of this capital in the centre of a large trough-shaped district,—with a series of important water-bearing strata beneath, and cropping out in successive zones around it,—is, at all events, very remarkable.

158. With regard to the *quantity of water* actually supplied by any known portion of the Tertiary district in this country, and by strata of the same age, as well as by the Lower Cretaceous deposits, in France, we have but few definite facts. Within a limited area in the valley of the Wandle the Lower Tertiary sands furnish probably not less than 1,000,000 gallons of water daily. Four wells in the Lower Tertiary strata at and near the small town of Vaires, in the department of the Seine et Marne, produce rather more than $2\frac{1}{4}$ million gallons daily.* In the Tertiary district of the neighbourhood of Perpignan, Artesian wells are numerous, and

* Degousée, 1847. See also Appendix A, p. 198.

probably furnish a large supply of water; the yield from one of them (which is however quoted on account of its being unusually great) amounted to 633,000 gallons daily.*

At and near Tours there are, in the Lower Cretaceous series (the outcrop and dimensions of which are apparently not very large), fifteen Artesian wells yielding, it would seem, together about 4,000,000 gallons of water daily:—the single well at Ville-aux-Dames supplying as much as 950,000 gallons in the twenty-four hours.† At Elbœuf, where these strata are also of moderate dimensions, the supply may possibly amount to 2,000,000 or 3,000,000 gallons daily; but I know the product of three only of these wells,—amounting together to about 800,000 gallons. The well of Grenelle, which merely indicates but does not measure the capability of the Lower Greensand, the thickness and outcropping surface of which are small in comparison with those of the same series in England, gives 880,000 gallons of water daily.‡ (See Appendix A.)

159. In inquiring into the probable relative value of any water-bearing strata it is necessary to compare the rain-fall in their respective area. We have seen (p. 110), that in the *Tertiary* district the mean annual fall averages 25 inches, whereas on the *Upper Greensand* it probably amounts to 28 inches, and on the *Lower Greensand* to 26½ inches. In the Tertiary district around Paris, the mean annual fall is rather more than 22 inches; and in the Greensand districts to the east of it, apparently rather less.§ (See p. 205.) Then again the distribution of the rain-fall according to seasons must be taken into account, for Mr. Dickinson's experiments show that little or no rain passes beneath the surface during the months from April to September inclusive. In this country the limited

* Arago, 1835.

† Degousée, 1851.

‡ I believe that these gaugings are mostly taken at or near the surface of the ground; when the jet is carried higher, the delivery will of course be less.

§ The facts connected with the meteorology of France, I have based upon the lists and data given by M. Charles Martins, in "Patria."

evidence we possess does not appear to indicate any material difference in this latter respect between the several districts; but between this country and France the difference is more marked—the annual rain not only being greater in England, but also the proportion falling during that period of the year, when it is less affected by evaporation and vegetation, being rather larger.

Taking the divisions of the seasons as given in the work of M. Martin, (which are not however so conformable as I would have wished with the periods of maximum and minimum infiltration,) the following is the relative distribution of the above-mentioned rain-falls :—

	Spring. March April May	Summer. June July Aug.	Autumn. Sept. Oct. Nov.	Winter. Dec. Jan. Feb.
	Per cent.	Per cent.	Per cent.	Per cent.
France, north of the Loire . . .	22·5	30·5	27	20
London and the neighbouring district .	21·5	26	31	21·5

160. The total superficial area of the Upper Greensand occupies 173 square miles, and that of the Lower Greensand 650. The average fall of rain on them amounts respectively to about 191,000,000, and 695,000,000 of gallons daily (for the extent of the effective areas, see ¶ 92 and 93). As also the thickness of the one formation averages 50 feet, and that of the other 367 feet, the latter consisting in great part of the most perfectly permeable strata, I cannot but think that, taking the question in all its bearings, — considering the results obtained from strata of much more limited dimensions,* and the relative fall of rain in the several dis-

* M. Degousée, the eminent well-engineer, has arrived at the following conclusions with respect to these several formations on the continent. After speaking of the drift deposits and their land springs, he observes,—"Les terrains tertiaries offrent déjà des bassins plus étendus, des couches mieux déterminées et des eaux plus pures; mais c'est dans les terrains secondaires que les phénomènes, dont l'art du sondeur tire parti, se présentent sur une plus vaste échelle, à raison de la grande épaisseur des couches, de leur alternances de moins en moins fréquentes, de leur continuité qui s'étend sur des cirques immenses, et aussi de la force des cours d'eau inférieure;

tricts,—we have, in these facts, a further argument in favour of the conclusions to which we arrived in § 12; viz., that a daily supply of from *six to ten million gallons of water* might be drawn from the *Upper Greensand*, and of from *thirty to forty million gallons* from the *Lower Greensand*, beneath London, and within a circle of five miles around it.*

For these large supplies the open texture of the sands themselves affords naturally the necessary channels and reservoirs. All parts of the surface can communicate freely with the subterranean reservoir, which presents a capacity for storage comparatively unlimited in its extent. If it were not to rain for a whole year, the effect upon the volume of water held in the strata would scarcely be perceptible; for let it be borne in mind that the effective permeable beds of the Lower Greensand are 200 feet thick, that they occupy an area above and below ground of 4600 square miles, that a mass of only 1 mile square and 1 foot thick will hold more than 60,000,000 gallons of water, and some idea may be then formed of the magnitude of such an underground reservoir. A fall of 1 foot in the water-level throughout the whole area of outcrop would give more than the quantity of water required for a year's consumption of London.

It is possible also, as mentioned below and also in ¶ 94 to

toutes ces causes rendent les sources naturelles de terrains secondaires plus rares et plus abondantes, et assurent aussi le succès de l'opération, qui consiste à les rechercher à des grandes profondeurs." Guide du Sondeur, p. 47. I was not aware of this corroborative passage until the conclusions mentioned in the text had been written.

* It is probable that a *very large additional supply* might be obtained by directing the water, which in heavy rains flows in considerable quantities from off the slopes of the chalk escarpments, to the outcrop of the Upper and Lower Greensands, and retaining it there so as to admit of its gradual absorption by those deposits. As the Lower Chalk almost invariably forms sloping surfaces towards the Greensands, the quantity to be furnished by such an extent of gathering ground might amount to several million of gallons daily.

In considering the productive power of the Lower Greensand, the lower division of it in Surrey and Kent was excluded. Should this division be reached beneath London, it is a source from which also a further very considerable addition to the water-supply might be expected.

96, that by employing artificial means to divert and collect the rain-fall from off adjacent areas, the quantity of water to be obtained through the Greensands might be greatly increased; whilst, should it be found practicable to traverse the Lower Greensand, other water-bearing strata, capable of furnishing large additional supplies, would probably be met with still lower in the Secondary series.* At a depth of 3000 feet, the temperature of the water would probably be above 100° of Fahrenheit.†

* The following may *possibly* be the succession of strata beneath London. I have taken, as the approximate thickness of the different groups, measurements considerably less than those assigned to them at their outcrops; for the Wealden formations thin out to the north, while the oolitic deposits appear to become less important as they range eastward, so that the strata of both series are probably thinner beneath London. The permeable arenaceous deposits are given *in Italics*.

	Thickness. Feet.	Depth. Feet.
Estimated depth to the Upper surface of the Lower Greensand (see p. 142)		1040
Lower Greensand	400	
Weald Clay	300	1740
Hastings Sands	260	
Purbeck Limestones	30	
Portland { Stone	20	2050
Portland { *Sands*	40	
Kimmeridge Clay	400	
Coral Rag	30	2520
Calcareous Grit and sands	50	
Oxford Clay	300	
Great (Bath) Oolite, Cornbrash, Inferior Oolite, Fuller's earth, &c.	200	3270
Sands of the Inferior Oolite	30	
Lias	300	

The Hastings Sands crop out in a broad tract of country ranging from Hastings, Tunbridge Wells, to near Petworth, and may be from 400 to 500 feet thick. The Portland sands, Calcareous grit, and Inferior Oolite, stretch from a base extending between Bath and Swindon, through Oxfordshire, Northamptonshire, into Lincolnshire. The dimensions of the sands of the Inferior Oolite are, in some places, considerable. The water from the Hastings sands and Portland sands would probably be very pure and good: the others more uncertain. The temperature of the former would possibly reach about 80°, and that from the sands of the Inferior oolite about 105°. Subordinate small water-bearing beds might present themselves in other parts of the series.

† As before mentioned, the temperature of the waters from the Greensand will probably be found between 65° and 70° of Fahr. (p. 172). I do not conceive that this would present a difficulty, as the water could be readily cooled by the refrigeration produced by exposure during night, and by its passage through the delivery pipes to the temperature required for use. Such water would not be flat, as might be the case with water warmed on the surface.

161. We have seen (§ 15) that the water-level in the Upper Greensand in Wiltshire stands commonly at about 300 feet above London, in Surrey at from 100 to 200 feet, and in Oxfordshire and Buckinghamshire from 120 to 300 feet, and that although rather lower, in the Lower Greensand of the latter counties, it is much above that level still:—further that the outcrop of the Upper Greensand is on the average, 150 to 200 feet, and that of the Lower Greensand 100 to 120 feet above that of the Lower Tertiaries, the water from which, when in their normal condition, rose above the level of the Thames, and yet overflows in the neighbourhood of London. We also have shown that, after allowing for all the difficulties of transmission, &c., the waters held in these formations would, if liberated by means of Artesian wells, probably rise above even the highest parts of the Metropolis,—perhaps to a *height varying from* 100 *to* 150 *feet* above the level of Trinity high-water mark.*

The column of water at Grenelle has been found to rise in an iron tube 120 feet above the surface of the ground. At Tours (the outcrop of the water-bearing strata not being many miles from the town, but its exact distance and relative height have not been given), some experiments, made at the Cavalry barracks in that town, to determine the height to which the water of an Artesian well would rise through apertures of different sizes, gave the following results:—

	Inches.		Feet.	
Through an aperture of	2·34	the water rose	11	above the ground.
" "	1·33	"	27½	" "
" "	0·43	"	38½	" "

162. One of the objections to the Artesian system has

* As natural fountains these springs might contribute to the ornament of London, but a yet more important application, under this high pressure, would be the scouring and cleansing of its courts and alleys by a general distribution of stand-pipes. Even should the water not be potable, still, for these objects, the comparative facility with which it may be procured, and its freedom from organic impurities, should, I conceive, render such sources deserving of consideration.

been that *the quality of the water* is not adapted to general purposes; for although the water from the chalk and Lower Tertiary sands is perfectly limpid, soft, and free from organic matter, far purer than the shallow spring water, and a better detergent than the river waters, yet it contains too many alkaline salts, and leaves too much solid residue. In new wells also it is often impure (Appendix C, p. 218). These conditions have in England created an unfavourable impression as to the quality of Artesian well water; a different opinion respecting it prevails, however, on the Continent, where these wells are in more general use.

It is probable that, *cæteris paribus*, the subterranean waters may possess to a certain extent the relative qualities which characterise them on the outcropping surfaces of the several water-bearing strata. In the chalk districts however the water is usually hard, but it is elsewhere (p. 219) shown, that what is found in the chalk beneath London exhibits a remarkable change, containing little or no carbonate of lime, and being soft and alkaline. The origin of this change, whether effected within the chalk itself, or produced by infiltration of the water from the Lower Tertiary sands or from the Thames, is too uncertain to be admitted in evidence of corresponding changes in other formations.

163. It is possible that the character of the water of the *Upper Greensand* which, on the surface, is likewise hard, may become modified in its passage underground. This water would also be free from those interferences which affect the deep chalk water. The arenaceous and permeable portions of this formation so much resemble the strata supplying the water to the well of Grenelle (which is *remarkable for its purity*), that we may look to some approach to a similar excellence in the waters of the Upper Greensand beneath London.

The waters in the Lower Greensand districts I believe

to be generally much above the average quality of surface waters. In the western part of Surrey, and also in Bedfordshire and Buckinghamshire, they appear to be especially pure and good. That they maintain this character in their subterranean position under London has been shown to be probable (¶ 140—142).

We know that at Cambridge, where the Lower Greensand is at a depth of 130 to 150 feet, and distant six or seven miles from its outcrop, the water obtained from it is, on the whole, very good, and in general use. The two specimens which were carefully tested seemed pure, and indicated 8·8° and 11° of hardness; and this probably would have been less had the water not stood in open shafts.* (Note p. 168).

164. With regard to the general character of *Artesian well waters in France*, and to the opinions held respecting them, I will make a few observations; premising that, although so different in geological position, a prominent feature of the water-bearing beds of the Lower Tertiary series in France is the presence of green and of light-coloured quartzose sands,—mineral peculiarities common to our Lower Greensand.

Both M. Hericart de Thury† and M. Degousée bear testimony to the almost invariably good quality of the water

* Cambridge is the only town, not upon the surface of the Lower Greensand, which derives a large supply from that deposit in its underground position (130 to 150 feet underlying the Gault, see note, p. 167). Much of the water is evidently very pure and good; the defects which exist in some of the wells are such as may arise from causes not natural, and would not occur if the water overflowed at the surface instead of standing a few feet below it. It is to be observed also that this formation has in Cambridgeshire a mineral character less favourable than in other districts around London.

† M. Hericart de Thury observes in his "Rapport," &c. (see p. 10), "Combien de villes ont établi, ou font en ce moment (1831) établir des puits forés pour remédier à l'insuffisance de leurs fontaines, ou pour obtenir des eaux pures et invariables en quantité comme en qualité, en remplacement des eaux dures et séléniteuses des puits ou des eaux vaseuses que leur fournissaient leurs rivières une partie de l'année!" These observations refer to the towns of St. Denis, Tours, Chartres, &c. Speaking of the waters in the Tertiary strata he states that, "Elles sont généralement douces et de bonne qualité."—"Ces eaux dissolvent parfaitement le savon et cuisent très bien les légumes."

furnished by the Tertiary and Upper Secondary formations, but without giving any exact particulars,* more than that they are limpid, pure, and good, and are used for domestic purposes and in various factories in Paris.

Tours is now in a great degree supplied by water from Artesian wells, which traverse the chalk and end in the Greensand series. An analysis of this water will be found in Appendix A.;—M. Dujardin remarks that it contains air and carbonic acid, dissolves soap perfectly, is limpid, and fit for all the purposes to which rain or river water is applied.† M. Payen makes similar observations of the Grenelle water, which is, however, chemically purer than that of Tours, and states also that "he finds that this water leaves less residue than the purest river waters." His analysis shows that it contains only about $\frac{1}{10}$th part of the salts of lime found in the waters of the Seine,—that it is perfectly free from the sulphate of lime,—and that it is apparently as well aërated as most surface waters. Messrs. Abel and Rowney in their analysis of the water of the Artesian wells in Trafalgar-square, observe, "The purity of the water of Grenelle is most "remarkable; the amount of fixed constituents being only "about, $\frac{1}{7}$th of that which is found in the London waters"‡ (see Appendix A, p. 206).

M. Marcel de Serre's§ researches in the Tertiary districts

* M. Degousée has since furnished me with an analysis of the water from the Lower Tertiary sands beneath Paris. The water is not so pure as that of the Seine, but the analysis was made immediately after the well was finished (twenty years ago), and the water has much improved since (see Appendix A, p. 211).

† Annales de Chimie et de Physique, 3me ser. T. I. 1841. In 1848 MM. Boutron-Chalard and Henry observe of the same waters,—"Que l'eau n'a rien perdu de sa pureté et de ses bonnes qualités."

The attention paid by most eastern nations to the waters they use for drinking is well known. M. Rey mentions that the Turkish ambassador in Paris sent daily to the well of Grenelle for his supply of water. (It must, however, be observed that many of the Paris waters are very indifferent.) He also states that this water is valuable for steam engines from its not encrusting the boilers. "Le puits Artésien de Grenelle," Paris, 1843. ‡ Journ. Chem. Soc. Vol. I. p. 97.

§ "Notice sur les Puits Artesiens," Montpellier, 1830. M. Hericart de Thury says

of the south of France have led him to the same conclusion,—"that the waters are limpid, fresh, potable, boil and lather "well."

M. Girardin, the eminent Professor of Chemistry at Rouen, expresses the following opinions,*—"Of all potable waters the best, without doubt, is rain water,"—"After rain water, the "waters of Artesian wells are the purest; they are generally "abundant, and contain fewer salts than river and spring "waters." Speaking of the water of one of the Artesian wells at Rouen, he mentions that "it boils vegetables well, is "very good drinking water, dissolves soap completely, is very "detersive, and well suited for the washing and bleaching "of all sorts of tissues."†

The waters of the Artesian wells of Lille, Valenciennes,‡ and St. Quentin, are generally of a quality which is perfectly satisfactory to the inhabitants (see p. 209).

165. Sometimes, however, when the wells are first made, the water of Artesian wells is impure, but after an interval, varying from a few months to two or three years, it is almost always found to improve, and generally to become perfectly good. This is a phenomenon of frequent occurrence in the Lower Tertiary sands in some districts near London (p. 218),—wells which were neglected at first have since proved quite fit for use. At Cambridge the same fact has been remarked (note, p. 167), and in Paris it is very commonly observed in the Tertiary strata.§

of a well bored near Perpignan into Tertiary beds of "sable chlorité" (greensand), — "Que l'analyse chimique a prouvé que l'eau, qui dissout parfaitement le savon, est d'excellente qualité." The success of this work immediately induced twenty-five of the neighbouring proprietors to project similar wells on their grounds.

* Leçons de Chimie élémentaire appliquées aux Arts industriels, p. 58, 59, Paris, 1846.

† Précis analytique des Travaux de l'Académie des Sciences de Rouen, 1830.

‡ The flax for the fine lace of Valenciennes is weathered in Artesian well-waters, their limpidity and even temperature being considered as of essential advantage.

§ "Mais il est un fait constant, c'est que dans une grande quantité de points où les eaux ont été employé pour des lavoirs publics, après avoir été au commencement

This improvement in the water is readily understood, and probably applies generally, from the constant flow of water through the same channels gradually removing all the soluble salts it meets with in its passage. In the Lower Tertiary strata around London there is also a source of impurity that would not exist in the Greensands, arising from the circumstance that in the former series, which on the whole is of marine and æstuarial origin, there is intercalated a group of fluviatile strata. At Woolwich, Blackheath, and Lewisham, they are fully developed, and they have been found to range in decreasing thickness under the greater part of London. Now as this ancient river bore down into the sea a great number of shells and a considerable quantity of vegetable matter, the calcareous materials of the one, and the deoxidizing action of the other (on the sulphates especially), would, independently of any other substances brought down by the river, tend to produce great local modifications and variation in the mineral character of the accumulating strata, and to lead to the formation of a number of soluble salts, from which the Upper and Lower Greensands, being entirely of marine origin, would be free.*

166. A very happy application to improving the water-supply of a large town has recently been made at Venice, which formerly was entirely dependent upon the fall of rain for its supply of fresh water.

The expense and inconvenience of this system had led (between 1825 and 1836) to various ineffectual attempts, on the

tout à fait impropre au lavage du linge, elles ont fini par devenir assez bonnes pour que leur usage soit préféré à celui de l'eau de l'Ourcq."—Letter from M. Laurent Degousée.

* It is however to be observed that the fluviatile and æstuarial beds form an upper division in the Lower Tertiaries; but the whole series is too permeable, and the line of separation too ill defined, to suppose that the waters they respectively contain are kept separate; or rather, it is probable that it is where this upper division expands, at the expense of the lower one (as happens to the north and west of London), that these effects are most apparent.

part of the Austrian government, to construct deep Artesian wells. In 1846, M. Degousée was applied to by the Municipality of the city, and after a careful inquiry into the practicability of such works in so peculiar a situation, and into the geological structure of the surrounding district, he engaged on the undertaking in 1846.* The works have been completely successful. At a depth of from 200 to 220 feet he reached a spring of water which rose about 23 feet above the surface of the ground. This water is apparently of good quality, and perfectly free from all infiltration of sea-water.† It is now in general use at Venice, the daily supply from 10 wells amounting to about 400,000 gallons. Of the dimensions of the water-bearing strata there are no means of judging; they appear to be small. M. Degousée is of opinion that they outcrop in the neighbourhood of Vicenza, Treviso, and Palma-Nova, at an elevation of about 50 to 70 feet above the surface at Venice; but he is now making an Artesian well 982 feet deep, by means of which he hopes to obtain water through strata which crop out at the foot of the Sub-apennine hills.‡

167. Lastly, with regard to the objection which has been urged against the Artesian-well system on account of the *gradual decrease* that has been experienced *in the quantity* of water which these wells have furnished. This is to be accounted for,—1st, by defects of the tubes, or by their becoming choked with sand; 2nd, by the relation between the supply and demand not being properly maintained.

168. On the first point I may briefly observe that many of the early wells around London were, I am told, tubed merely with common tin pipes; that they should have got

* Bulletin de la Société Géologique de France, 2ème, ser. T. VII. p. 48, 1850.

† This water has been analysed by the "Faculté du Royaume" at Padua, and found to contain per litre,—carbonate of lime 0·129, carbonate of magnesia 0·036, carbonate of soda 0·018, oxide of iron 0·013, organic matter 0·021, chloride of potassium 0·005, total 0·222 grammes; or about 15½ grains per gallon.

‡ Artesian wells have long been in use in several towns of northern Italy.

out of repair and use is not surprising. Even where iron is used the action of the London clay is often very rapid in its corroding effects.*

Defective construction of the pipes in some wells, in this and other respects, and a want of sufficient power in the ascending jet of water in others, or frequently both causes jointly, has led to the gradual accumulation of sand in the tubes of many Artesian wells, and thus materially interfered with their supplies, independently of any fluctuation in the water-level.

This indeed is an inconvenience of very general occurrence in Artesian wells drawing their water from beds of sand, unless the jet of water be very powerful, and then it will keep the tube free. The spring often diminishes, and sometimes ceases to flow, apparently from a decreasing supply, but in reality from the above-named cause. The Artesian wells in the Tertiary strata at and around Paris are very subject to this cause of obstruction. It is, however, easily remedied by the removal of the sand out of the tube, when the water will resume its original rate of flow. It is a defect, also, which almost ceases to operate after a time, especially where the spring is strong; as the water, by bringing up the sand, gradually excavates a permanent cavity at the base of the bore.

With regard to the Upper Greensand, its more compact and solid beds would transmit, through fissures, the water received in its more sandy strata at a distance, and the inconvenience from this source would probably be small. A cavernous rocky frame-work would soon be established, which would form a well-adapted receptacle for the water, and keep back the sands.

In the case of the Lower Greensand, this inconvenience at first might be considerable, but the force of the flowing water

* At Sutton a wrought iron pipe has been recently taken up after seven years' use. It was found to be quite worn through.

would no doubt ultimately always tend to remove the obstructions, and to keep the channels clear.

169. We now have to consider the more important question *relating to the supply and demand.* So long as the quantity of water taken in the course of the year from a water-bearing stratum does not exceed that which it receives of the mean annual rain-fall, and it is not abstracted more rapidly than it can be replaced by percolation, so long will the equilibrium be undisturbed, and the spring maintain a steady and undiminished flow. It is the continual additions supplied by rain, and not the bulk with which the strata are saturated (which quantity should remain constant), that must form the really available source of supply. For if a water-bearing deposit, into which 5,000,000 gallons of water annually pass by infiltration at its outcrop, should have 10,000,000 gallons taken from it in the same time by means of Artesian wells, the extra 5,000,000 will be a drain upon the quantity required for the full saturation of the strata, and an encroachment upon that which should be considered as a permanent reservoir,—any decrease in which, by diminishing the pressure, will tend to impede the percolation of the water, and consequently to lessen its flow and delivery from the subterranean strata. If this system—of an abstraction more rapid than the replenishment by rain—be continued from year to year, the result must be an exhaustion of the strata, a gradual fall in the water-level, and a constant decrease in the supply.

This is a process now taking place, although not exactly in the above proportions, at London. The chalk, notwithstanding its large dimensions, is not a freely permeable deposit; the Lower Tertiary sands, on the contrary, are freely permeable, but of very limited dimensions. Consequently they are both unable to meet the demand which is made upon them, they are both over-drained, and exhibit a fall varying from about 40 to 60 feet in their water-level within the last thirty years.

But this fact cannot be made a valid ground of objection against the system generally. Let the demand upon any series of strata be carefully regulated not to exceed the *mean annual* supply by rain, and then the yield will not fluctuate.

170. In the Lower Greensand we have a mass not much inferior in volume to the chalk, and in permeability far surpassing even the Lower Tertiary sands. In the Upper Greensand the volume is smaller, but yet it is one very far exceeding that of the Tertiary strata, and with a power of transmitting water nearly equal to them. Therefore that these are sources from which large supplies may be obtained is reasonably to be expected.

Nor are we entirely without independent evidence of great quantities of water existing in strata of sand. A very remarkable instance is mentioned by Mr. R. Stephenson, of a case where such a stratum yielded by two shafts, *fourteen million gallons of water daily*, and this notwithstanding that it was in a district much disturbed by faults, where the continuity of the strata is often broken; and where it is not probable that the sand-bed could have been more than a few yards thick.*

171. With respect to the *permanence of supply* by means of Artesian wells, Arago merely adduces two cases, which he seems to consider conclusive,†—viz., the Artesian well at Lillers (note, p. 192), and that at the monastery of Saint André,‡ which latter at this day seems, with regard to the

* "In the county of Durham, two shafts, within a few yards of one another, are "now in process of being sunk for the purpose of a coal-pit. They have encountered a "stratum of sand lying between the Magnesian Limestone and the Coal Formation, "abounding with water to an extraordinary degree. For some months past, and up to "the present moment, more than 10,000 gallons per minute, or 14,000,000 per twenty-"four hours, have been pumped from the stratum of sand crossing these two shafts." —Mr. Stephenson's Second Report to the Directors of the London, Westminster, and Metropolitan Water Company, p. 12, 1841.

† Annuaire, 1835.

‡ The tubes of these old works are apparently of oak.

height of the jet and the delivery of water, to be in the same state as when observed by Bélidor more than a century since.

There are a great number of Artesian wells in the Tertiary strata of Paris, and I am informed by M. Degousée that they keep, relatively to the Seine, a level nearly constant, or of about 6 feet below the surface of the ground in the lowest parts of Paris;—that he has not yet observed the slightest difference in the natural level of the water;—that even in wells constructed twenty years since, he has never had occasion to shift the pumps, although the number of wells have multiplied a hundred-fold (centuple). In the neighbourhood of Paris several wells have ceased to flow, but that is generally owing to defective construction, or to the tubes becoming clogged with sand.* Under, however, proper conditions, the yield generally continues as good as at first. M. Degousée, writing in 1847, mentions, also that at Meaux he sank, between 1833 and 1838, eight wells, in the yield of which no variation has since been perceptible.†

At Tours the increase in the number of the Artesian wells diminished for a time the supply of some of the older wells, but for the last eight years not the *slightest change* has been perceptible in their yield of water. At Elbœuf there has been, I believe, a greater variation, but I do not know to what extent. M. Hericart de Thury‡ also mentions several cases confirming generally the permanence of the supply from

* "Quelque fois un peu d'ensablement a eu lieu à la base de la colonne d'ascension, mais il a toujours suffit d'y descendre une soupage retirant les sables pour rendre aux puits leur écoulement normal." L. Degousée, 1851.

† He likewise remarks,—" Une grande partie des puits artésiens que j'ai fait ont augmenté, et quelques uns ont doublé de produit. D'autres ont subi de grandes diminutions provenant de l'établissement dans la même localité, de nouveaux sondages, avec lesquels les premiers se sont mis en équilibre de niveau et de quantité; les anciens puits isolés qui ont également diminué, tant ceux exécutés par moi que par d'autres sondeurs, sont assez rares, et la cause de cet affaiblissement doit en être attribuée à la crainte qu'ont eu les propriétaires de faire les dépenses nécessaires à leur bonne confection. Nul doute que s'ils étaient réparés, ils ne reprissent leur ecoulement primitif." Guide, p. 184.

‡ He instances the well at the Ecole Militaire of Paris, which is in the Lower

these sources. The well of Grenelle continues now to deliver the same quantity of water as at first.

172. Although the level of the water in the deep wells in London has fallen so much, the variation at a short distance from this centre has been comparatively small; in Essex it appears to be trifling, and in many places imperceptible; at Garrett, Merton, and Tooting the difference during the last twenty years has not amounted to more than a few feet; at Edmonton and Waltham Abbey to still less. At Cambridge, when it is considered that the number of Artesian wells in so circumscribed an area is estimated from 500 to 800 or more,* the fall of 10 to 12 feet, which is

Tertiary strata, and was bored in 1775. Writing in 1829, he observes,—"Depuis, l'eau s'est constamment maintenue de huit à dix mètres au dessous du sol:" and of a well in the Rue de Bondy, sunk in 1780,—"Au moment du percement du dernier banc de grès, l'eau jaillit par-dessus la tête des ouvriers; mais elle s'abaissa ensuite peu-à-peu, et depuis elle n'a jamais varié et se maintient à fleur de terre." Another well, at the glacière de Gentilly, constructed in 1818;—a bore of 19 metres,"fit jaillir les eaux jusqu'à la surface du sol, elles se sont depuis constamment maintenues à 0·60^{m} environ, au dessous de la margelle." Again,—"Il existe à Lillers un puits foré établi, dit-on, en 1126, dans l'ancien couvent des Chartreux, et qui n'a jamais varié dans le beau volume d'eau qu'il donne au-dessus de la surface de la terre. Outre ce puits, on en compte plusieurs autres à Lillers. La profondeur varie depuis 10 jusqu'à 20, 30, et 40 mètres. Les eaux sont dans la partie supérieure de la masse de craie; elles sont d'excellente qualité et ne présentent aucune variation." "Rapport sur les Puits Artesiens," &c.

* Mr. Deck, on the authority of a builder in large practice, and of local well-diggers: he further mentions,—

"In 1812 the first Artesian well was made in Cambridge, the water *then* was propelled from the bore nearly 4 feet from the surface; a succession of bores since made rapidly reduced the flowing *above* the surface, and as a very large proportion of water used in the town is *now* derived from this source, the water stands in the wells from 6 to 12 feet *below* the surface. I am not aware of any nearer than 8 feet: a good supply is to this point obtained. The number of bores cannot well be estimated—certainly above 500. The nearest position at which the stream flows above the surface is at Barton about three miles from Cambridge, in a direction nearer to the surface source, from whence the Lower Greensand is supplied. For the last six years a bore 3 inches in diameter has, without any *apparent fluctuation*, discharged a continuous stream 3 *feet from the surface*. The Barton water is much impregnated with iron. In the same direction twelve miles further towards the source, at the village of Whaddon, is a bore from whence is discharged, from an iron pipe, 3½ inches in diameter, 6 feet from the surface, a continued and *forcible* stream of water, rising by its impetus 12 inches above the aperture of the pipe, and discharging from 20 to 30

said to have taken place during the last forty years, is rather an indication than otherwise, of the great water capacity of the Lower Greensand formation, even so near its outcrop and where the difference of surface level is so small. But still this excessive local draught does not affect the overflow from an Artesian well at a distance of three miles, and that in the direction in which the waters travel underground.*

It is probable, that as the force of projection is rather limited, the tubes become partially blocked up with sand, which impedes the full rise of the water, within a short time after the construction of the wells: the slight extent to which this operates shows, however, how strong the *head* of water must be. It even seems to me very doubtful whether

gallons per minute of very excellent water. No diminution has been observed at any period of dry or wet weather, except when a bore was made at Airington,[1] about four miles distant from Whaddon. This stream rises 5 feet above the surface from a bore 4 inches in diameter, and the water has ferruginous impregnations. The Whaddon bore has been made upwards of twelve years."

* As an instance of a permanent water-level in a deep Artesian well, drawing its supplies from the chalk, and as an extremely well-designed application of the system, I would refer to the Artesian well suggested by Captain James, on good geological data, to remedy the want of fresh water experienced at the Blockhouse Fort, Portsmouth. As this fort stands on a slip of land projecting into the harbour, it is nearly surrounded by the sea, and is only a few feet above the level of high tide. Great care was consequently necessary to keep out the salt water, which was accomplished by means of iron cylinders; and after boring through between 500 and 600 feet of Tertiary strata (very much the same as the lower part of the series at Alum Bay in the Isle of Wight), and a few feet into the underlying chalk, a spring was reached from which the water rose to from within 4 to 5 feet of the surface. I am informed by Captain James that it has steadily maintained that level since (1848), although other Artesian wells have more recently been sunk at Portsea; that the supply is abundant and of good quality; and also that the action of the tide on the well is remarkable, the water falling and rising 1 foot, but not until *three hours later* than the ebb and flow of the tide at Portsmouth itself. This must depend upon the outcrop of the chalk in the sea off Culver Cliff in the Isle of Wight.

[1] In a subsequent letter Mr. Deck states, "that the diminution of water, observed at Whaddon, by the boring of this well, was shortly afterwards increased to its original strength, and has remained so the last eight years;" that the many wells bored at Cambridge have had no effect upon the Barton overflowing one; "the abstraction (at Cambridge) must be very great, and *very little, if any diminution* is observed; if much, it has *always been found to proceed from the filling up of the bore by extraneous matter.*"

the fall at Cambridge actually exceeds 2 or 3 feet, or if so much; for on further inquiry, I find that in two instances of wells recently bored, the water in both cases *rose at first above the surface.* In no instance has a well been known to be pumped dry, even by pumping for hours at fires, &c.

Some Artesian wells have even increased their supply; instances occur both in this country and in France. In one case there was an increase, in the course of a few months, from 25 to 75 cubic metres, and ultimately to 120 in the twenty-four hours.*

173. It has been a question whether an increase in the number of the wells within a limited area would lead to a corresponding increase in the total quantity of water obtained. It is proved that in some of the older and more compact strata in which the water is held in fissures, the delivery is but very little increased by multiplying the wells. But this is not the case with loose arenaceous strata. At Cambridge I am informed that the supply in the wells remains the same, that it does not appear to diminish, although numerous fresh bores are constantly made.

* In the Philosophical Transactions for 1785 (vol. 75, p. 1) is a paper of Dr. Erasmus Darwin, entitled "An Account of Artificial Springs of Water," and containing some interesting observations bearing upon these questions. At a distance of half a mile from Derby, and on a level 4 to 5 feet higher, is "St. Alkmund's well." Observing that the strata of red marl rose in that direction, and having a bad supply of water at Derby, Dr. Darwin conceived that, by boring to a certain depth, he should find the same spring which supplied St. Alkmund's well. He accordingly bored 51 feet, and at that depth obtained a supply of water which flowed 1 foot over the surface, at the rate of 2 hhd* per day. Dr. Darwin thus continues, "The new water has now flowed twelve months, and, as far as I can judge, is already increased to almost double the quantity in a given time; and from the rude experiments I made, I think it is now less replete with calcareous earth, approaching gradually to an exact correspondence with that of St. Alkmund's well, as it probably had its origin between the same strata of earth." He then proceeds to make some sound and good remarks on the effects of the elevation of the land, and the tilting up of strata on hill sides; on the infiltration of water and its issue in the form of springs; and concludes that "it is probable that the older and stronger springs are generally the purer," and also that springs may widen their channels and become larger. I find that he also treats Artesian wells as "artificial springs of water."

In a well bored into the Lower Tertiary sands at St. Ouen near Paris, a jet of water was obtained furnishing about 26,000 gallons in the twenty-four hours; another well was afterwards made in the same strata, and at a distance of 170 feet from the former one; and M. Hericart de Thury observes in 1829, the "jet of water (at this well) gives about double the "quantity obtained from the same spring at the first well, the "delivery from which has, however, experienced no diminution." The instances, before mentioned, to show the permanence of water-level, are proofs of the same fact.

174. In conclusion, I consider, that, under proper restrictions against its indiscriminate use, and with a due regard to the construction of the tubes and their maintenance in good condition, *the supply of water from the Greensands may be permanent and continuous.* In fact, the operation of the system would tend to ensure stability; for the underground currents of water would form for themselves, in process of time, channels as fixed and definite as those in which the waters flow on the surface of the land. But to obtain such a result, it is as necessary underground as above ground, that the same volume of water should continue to circulate in the same channels, so as to maintain a constantly equal eroding force; otherwise, as in rivers, a decrease in the volume of water will lead to a silting up of the channels.* (See § 15.)

With the constant and uniform flow of springs issuing along lines of fissure on the fractured surface of the earth, we are well acquainted; many of them are but natural Artesian wells (see Appendix B). No diminution is known in their delivery, and no appreciable difference has been detected in their quality. They have flowed for ages past, and promise to

* I cannot too strongly insist upon the importance of regulating and restricting the supply; for large as I believe it would prove to be, still an indiscriminate use of it would necessarily, after a time, destroy its permanence and value. Under a properly adjusted system all the tubes should deliver at the same height, otherwise the lower ones would gain power at the expense of the others.

flow for ages to come, with the same power and volume, and are to be placed amongst those beautiful provisions of natural laws designed for our permanent use and advantage. They are apparently subject to no greater variations than rivers, and apart from the inevitable changes accompanying physical action on the surface of the earth, are as durable as other like operations of nature.

175. If such be the resulting phenomena of a like class of causes naturally, I apprehend that by means of a well regulated system of adjustment, an equilibrium equally well maintained may be established artificially, and with a prospect of equal permanence. Indications of such stability we have already perceived in the Artesian fountain of Lillers, which dates from the twelfth century; and still more, if Lamartine be correct, in the fountains of Solomon at Tyre. It is even not improbable that many of the old and celebrated wells of the East may prove to be Artesian,—true artificial *springs* in permanence and excellence of supply.* The failure of the system, when the above-mentioned laws have been disregarded, cannot be considered as an argument against its durability; for even in those constructions on the surface, designed for the same object, and under our immediate and constant inspection, the revolution of ages brings about changes equally great.†

* The art of their construction having been known to the Ancient Egyptians, may have been practised by them or their contemporaries in many parts of Asia, where it has been now lost for many centuries. The Chinese have long been acquainted with the system of Artesian wells.

† The destructive effects of time are not more apparent in the simple Artesian wells of the ancient Egyptians than in the massive aqueducts of the more modern Romans. Many of the old wells in Egypt are even yet in a state which admits of restoration. Aymet Bey has, since 1830, removed at several places the obstructions which encumbered them, supplying desert tracts with water, and bringing back a population as of old. The construction of these wells he dates back nearly 4000 years. Annales de Chimie et de Physique, Vol. LXXI. p. 201, 1836.

APPENDIX A.

On the Artesian Wells in the Tertiary and Cretaceous districts of the North of France.

In the old county of Artois, and the adjacent tracts of the North of France, Artesian wells have long been in common use. Although known at a few other places, it is only since the commencement of this century that they have become general elsewhere in France, and in other countries of Europe.*

The greater number of these wells in that district derive their supplies from the upper beds of the chalk;†—this formation being very generally overlaid by the clays and sands of the Lower Tertiary strata, which rarely attain any great thickness, and are on the whole impervious, although containing occasionally subordinate water-bearing beds. These circumstances render the construction of such works in that country easy and expeditious.‡

In other parts of France, and more especially in the Dé-

* Cassini, in the beginning of the 18th century, notices Artesian wells at Modena and Bologna, also at Vienna where they have long been employed.

† The chalk extends from the frontiers of Belgium on the north, to within a few miles of Poitiers and Bourges on the south; and from Troyes and Rethel on the east, to Le Mans and Havre on the west. Throughout a large central portion of this extensive tract it is, however, covered by Tertiary strata, and it is within their area that Paris is situated—an exact counterpart of the position of London. Vienna is also placed in the midst of a Tertiary area.

‡ M. Hericart de Thury states that M. Degousée commenced an Artesian well (in Tertiary strata overlying chalk, at Fontes, Pas de Calais) at six in the morning, and finished it at three the same day, at a depth of 20 metres.[1] The jet of water rose 2 metres above the surface, and supplied 400 litres per minute. "Rapport, etc.," 1831, p. 13.

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[1] 1 metre = 3·2808 feet. 10 litres = 2·201 gallons.

partement du Nord, as the chalk and the members of the Lower Cretaceous series, which are there very thin and unimportant, rarely yield a sufficient supply of water, it is generally necessary to sink through these strata (200 to 600 feet thick) down to the sands and sandstones of the carboniferous or other older rocks, to obtain the requisite supply.*

In the neighbourhood of St. Quentin, however, the Artesian wells derive their supplies from the Greensands. The wells are numerous, and M. D'Archiac observes in 1843 that, "Since their establishment the volume of water which "they supply has not sensibly diminished, and that no inter-"mittance has been noticed."† In the Département of the Somme there are a number of Artesian wells in the chalk.

South of Amiens the Tertiary formations gradually set in, and increase in thickness and number as they trend towards Paris.

The lowest division of this series consists of a variable deposit of clay (argile plastique) and sands. In these strata a considerable number of Artesian wells have been sunk in and around Paris.‡ Most of them yield a good, and many a very large, supply of water. In 1841, a well bored near Meaux to a depth of 44½ metres gave 1100 litres of water (243 gallons) per minute. The jet rose 3½ metres above the surface of the ground. Another at Brou on the Marne, 75 metres deep, supplied as much as 2500 litres per minute (nearly 800,000 gallons per twenty-four hours). It was constructed in 1845, and cost 5000 francs. M. Degousée states§ this to be the most remarkable result yet obtained in the Tertiary strata

* In this district these formations underlie the cretaceous series immediately,—the whole of the Oolitic and Triassic series being absent.

† Mem. Soc. Geol. de France, tom. v. p. 367.

‡ The Tertiary deposits in France are far more varied than in England, consisting of numerous alterations of Calcareous rocks, sands, sandstones, marls, and fresh-water limestones. They present as many as five distinct water-bearing strata. None of them, however, are so important as the lowest, in which the supply of water is almost always abundant.

§ Guide du Sondeur. Paris, 1847, p. 435–6.

around Paris. These, however, are extreme cases; but a supply of from 100 to 500 litres per minute is not uncommon. Some years since two wells were bored at Epinay, to a depth of 67 metres, only 1 metre apart; one gave 36,000, and the other 40,000 litres in the twenty-four hours. At St. Denis 300,000 litres per twenty-four hours was obtained from an Artesian well, but the supply has since diminished.

As a general rule, notwithstanding the number of these wells in the Tertiary strata, their yield of water remains comparatively unchanged, except when interfered with by defective construction, or by the tubes becoming clogged with sand,—both causes not unfrequently in operation (see notes p. 190).

Up to a late period all the numerous Artesian wells of Paris and its neighbourhood were confined to some of the water-bearing beds overlying the chalk, but the quantity of water from these sources having been found insufficient for some of the large public establishments, and the chalk itself in the Paris district not affording any supply of water,* the municipality of Paris resolved to bore *through* that formation, and seek for water in the underlying deposits. Some precedents already existed for such an undertaking, as in many places nearer the borders of the chalk district, as at Elbœuf, Tours, and St. Quentin, Artesian wells had been sunk successfully through this formation.†

The works were commenced in 1833, at the abattoir of Grenelle, and were continued, but with several long interruptions,‡ until 1841, when at the great depth of nearly 1800 feet, the water-bearing strata were reached, and a column of water, capable of being carried to a height of 120 feet

* Several unsuccessful attempts had previously been made in the neighbourhood of Paris to obtain water by Artesian wells within the chalk. One of the principal of these was at Suresne, where the works were carried to a depth of 170 metres.

† In 1845 M. D'Archiac stated that there were then 80 deep Artesian wells in and below the chalk.

‡ At the end of 1835 the bore had already reached a depth of 1300 feet.

above the surface of the ground, was suddenly projected.* The supply amounted to about 4,000,000 of litres, or 881,884 gallons in the twenty-our hours;—the temperature of the water being nearly 82° of Fahrenheit.†

M. Mulot informs me (April, 1850) that these conditions still remain unaltered.

The strata traversed were as follows:—

		FEET.‡
Drift,—Sand and gravel		33
Lower Tertiary strata		115
Chalk with flints	1148	1394
„ lower	246	
Calcareous sandstone, clays, and sands, ending with a bed of green-coloured sand		256
		1798

This well furnishes a valuable point of comparison with regard to the results which a similar undertaking in the vicinity of London might give. The surface of the ground at the well is 102 feet above the level of the sea. The French geologists consider the sands from which the supply of water is obtained, either as subordinate beds of the Gault, or as belonging to the Lower Greensand. They crop out in a zone of country about 100 miles eastward of Paris, and range along the segment of a circle, of which Paris is the centre, from between Sancerre and Auxerre, passing near to Troyes, thence by St. Dizier to St. Ménéhould. The outcrop of this formation is continued some distance farther north; it is also prolonged beyond Sancerre, south-westward towards Bourges, Chatellerault;—and then north-west to Saumur, Le Mans, and Alençon. But the superficial areas which it occupies in

* According to M. Rey the diameter of the tube at the top of the bore is 11 inches, and at the bottom 6·63 inches.

† Walferdin in the Bulletin de la Société Géologique de France, Vol. X. p. 431, Vol. XI. p. 28, and Vol. XII. p. 166; but the fullest particulars of this well, with notices of several others in France, is given by M. Rey in the "Revue de la Province et de Paris," for December 1843,—a notice since published in a separate form.

‡ Where the contrary is not mentioned, English measures are always employed in the tables and text.

these latter districts do not appear to contribute to the water supply at Paris, for the axis of elevation of Mellerault (which, according to M. D'Archiac, traverses the Cretaceous area in a north-west and south-east direction from Normandy to Burgundy) must intercept the subterranean passage of the water from the district south of that line;—whilst on the north of Paris the anticlinal line of the "Pays de Bray," and some smaller faults in the Aisne, produce probably a similar stoppage with respect to the northern districts. The superficial area, therefore, from which the strata at the well of Grenelle draw their supplies of water, forms, on the east of Paris, a belt stretching from near Auxerre to St. Ménéhould. How far the more limited outcrop of those beds in Normandy contributes to this water supply is doubtful.

The Lower Cretaceous formations in France differ considerably from their equivalents in England. They do not contain so great a proportion of sand as exists here. On the contrary, argillaceous strata with only subordinate arenaceous beds predominate. The Upper Greensand is tolerably well developed, attaining in Normandy* a thickness of 40 to 60 feet; but on the east of Paris it is so thin and unimportant, that it can scarcely be separated from the chalk and gault. No water was obtained in this part of the series at Grenelle.

The Gault in France retains much of the character it possesses in England, but is not in general so thick, nor so uniform in its structure, for it not unfrequently seems to alternate with beds of clayey greensand. As a mass, however, it

* M. de Caumont. "Essai sur la Topographie Géognostique du département du Calvados." I am here assuming that the bed which is in that work described as Lower Greensand is in reality our Upper Greensand. It is a very dark and persistent green sand, 40 feet thick at Canapville. At Hennequeville the gault is 60 feet thick, and overlies 20 feet of ferruginous sandstone (Lower Greensand ?). See D'Archiac, Mem. Soc. Geol. de France. 2nd. Ser. Vol. 2. p. 99—103.

M. Passy, in his "Description Géologique du département de la Seine Inférieure," assigns a thickness of 100 metres to the various divisions of the Lower Cretaceous series. Near Havre the Upper Greensand is 7 metres thick.

is argillaceous and impermeable.* In some places it would almost seem that the Gault passes into the Lower Greensand by the preponderance of sands. But still it appears to me that there is a sufficient division between the two, the sands of the former being local and irregular, whilst those of the latter are more uniform and persistent, and present a true water-level.

The Lower Cretaceous series has been divided by French geologists into the *Grès vert* and *Terrain Néocomien*. The latter, forming the lower and larger division, consists chiefly of clays, marls, and soft limestones, and presents an impermeable base to the former, with which alone we are now concerned. In the north-east of France this subdivision (Grès verts,—the equivalent of part of the thick and important mass of our Lower Greensand) is only rudimentarily developed, forming a bed of coarse ferruginous sand and grit a few feet thick. As it trends southward it gradually becomes thicker. In the department of the Aisne this deposit is, according to M. D'Archiac,† about 70 to 80 feet thick, and composed of green and yellow sands with subordinate clays, apparently in about equal proportions. In the neighbourhood of St. Dizier,‡ M. Cornuel assigns to it a thickness of about 75 to 90 feet, of which about 40 consist of green, yellow, and ferruginous sands.§ In the "Aube" M. Leymerie|| describes

* The gault varies considerably in its thickness, being frequently not more than 50 to 60 feet thick. At Vitry le François, M. Cornuel, reports that it (and the chalk marl ?) was pierced to the depth of 123 metres and not traversed.

† Memoires de la Société Géologique de France, Tom. V. See also the Papers of this author in the 3rd Vol. 1st Ser. and 2nd Vol. 2nd Ser. of the same Memoires, on the "Formation Cretacée," in which there is an excellent summary of the physical and palæontological characters of this group.

‡ For the purpose of seeing the general physical characters of the Lower Cretaceous in the north-east of France, I made, last summer (1850), an excursion through the districts of the "Haute Marne" and the "Aube;" it was, however, far too hasty to allow me to study details. My chief object was to observe the general characters of the country as compared with the aspect of our own Greensand districts.

§ These are divided into two, by a thick bed of clay. In the note in the next page M. Cornuel alludes only to the upper 20 to 33 feet of sand. Memoires de la Soc. Geol. de France, Tom. IV. p. 229.

|| Ibid, Tom. IV. p. 291.

the Lower Cretaceous series as 130 to 200 feet thick, and divides them into "argiles tégulines, and grès verts." The latter appear to possess a rather greater development than in the Haute Marne, but no exact details on that point are given. Proceeding further southward the sands become more varied, presenting whitish, yellow, and ferruginous beds, interstratified with strata of green sands and clays.

In Normandy there is some uncertainty about the limits of this group: it appears to vary from about 10 to 60 feet.

In the great Geological Map of France the whole series of beds, from the base of the chalk to the top of the oolitic series, is, without distinction, coloured light green. It is, therefore, difficult to know what portion of this area, which is a very large one, is occupied by the sands of the grès-verts, and forms the receiving surface by which the well at Grenelle is supplied with water.

Owing to the very slight angle at which the strata crop out, the breadth of this zone on the Map is as much as from ten to twenty miles. A large portion of it is occupied by the Gault, and another considerable portion by the Terrain Néocomien. M. Cornuel of Vassy considers that the tract formed by the Lower Greensand alone is not more than 3000 metres broad, and that, excluding the detached and unproductive parts, 1000 metres would probably represent its general and available breadth.* Northward of this district

* In a letter recently received from M. Cornuel, in answer to my inquiries, he puts the case very clearly in the following extract:—

"J'ai demandé à M. Roger, notre collègue de la Société Géologique, ce qu'il pensait des dimensions de l'affleurement des sables vert et jaunâtre de Louvemont et Allichamps, &c. Dans ses recherches, il a reconnu comme moi qu'il était très difficile d'assigner une largeur constante ou précise à cette effleurement, en raison de ce que le sol est très decoupé par les vallons et très couvert par le forêts, le diluvium et la terre végétale. Il pense, et je suis de son avis, que la largeur moyenne ne peut pas excéder 2,000 mètres, et que c'est peut-être dejà beaucoup. Cette largeur est très déchiquetée ou decoupée par les formes extérieures du sol ; c'est-à-dire qu'ici les val-

these dimensions decrease. If we take, therefore, an average breadth of 1000 metres, and a length of 140 miles, from between Auxerre and Sancerre, to St. Ménéhould, it will give an area of 77 square miles. At its western outcrop in Normandy, from near Mortagne to Havre, this deposit is less important. At a rough estimate its superficial area may be taken as not exceeding 25 to 30 square miles; and if we further take 10 to 15 square miles for its extent on the south side of the valley of Bray, we shall have a total of about 117 square miles occupied by the exposed surface of water-bearing beds supplying the well of Grenelle. But a larger portion of these strata, than in England, appears to me to be covered by drift, and thick vegetable soil. Judging from the general aspect of the two districts, and considering the allowances made here on that account, we may probably deduct (although this is little more than a mere guess) 47 square miles, leaving therefore the effective area represented by 70 square miles.*

The subterranean area in connection with these lines of outcrop may possibly be about 20,000 square miles; and the average thickness of the sands of the *Grès verts* serving, in their underground range, as a reservoir for the water, does not probably exceed 30 to 40 feet.

According to the Ordnance Map of France the height of the surface above the level of the sea, at some points of this Lower Cretaceous area, where it is traversed by rivers, is as follows:—

lons entament le sable et même l'argile sous-jacente, tandis que le sable reste avec toute son epaisseur ou même se trouve recouvert par des lambeaux de Gault. Il resulte de ces accidents que la partie de l'effleurement des sables de la Haute Marne qui reçoit les eaux pluviales et les eaux courantes, et qui les conduit souterrainement vers le centre du bassin de Paris, ne pourrait pas être représentée théoriquement par un affleurement *uniforme et régulier de plus de* 1,000 *mètres de largeur constante;*—" Je viens de faire tout exprès une course d'exploration dans notre région des sables pour mieux me fixer sur ce que j'avais à vous dire."

* I believe that it will prove to be less than this.

	FEET.		FEET.
The Aisne, at Rethel . .	230	The Seine, at Lusigny, nr. Troyes	332
The Marne, at St. Dizier . .	443	The Yonne, at Auxerre .	312

Between these points the ground rises into low hills, rarely more than 50 to 150 feet higher than these valleys. The general height of this zone of country does not, therefore, appear to exceed 250 to 500 feet above the level of the sea, or we may possibly take it at an average of about 400 feet.

M. Martin* considers that the mean average fall of rain in the inland parts of the north-western districts of France, (Climat Séquanien) deduced from observations at Paris, Brussells, Courtrai, Lille, Troyes, Denainvilliers, Chartres, and Bourges, is 21·5 inches (548^{mm}) annually. At Paris, the mean annual fall is 22·2 inches (564^{mm}). The quantity increases to some extent in proceeding towards the coast of the channel.

The main contributing surface to the Grenelle well is, however, chiefly to the eastward of Paris. The mean annual fall at four places, in or near that district, is as follows:

	Period of observation. YEARS.	Rain-fall. INCHES.
Chalons sur Marne	4	18·70
Metz	10	23
Auxerre	6	25
Bourges	19	20·27

It is evident from this table, that the fall of rain on that surface is several inches less than on the area of the Greensands in England.

The water at the Grenelle Artesian well has continued since its opening in 1841, to flow in undiminished power and quantity. At first it brought up so great a quantity of sand, that the tube was several times choked up by it, and even now it is not free from occasional, though rare interruptions; but the force of the column of water has always proved sufficient to clear its way after a short interval. It

* "Patria, La France ancienne et moderne," art. Météorologie.

now flows in a clear and continuous stream, and is carried by pipes to a reservoir near the Pantheon, whence it is distributed over the adjacent parts of the city, as well as along the line of the Boulevards from the Abattoir to the Observatory. By means of small branch pipes also the Ecole Militaire, the Invalides, and two or three other public establishments, are entirely supplied with this water, which is well aerated, pure, and wholesome. The aeration differs, however, from that of river waters generally, in containing more atmospheric air, and less carbonic acid.

M. Payen states that this water is well suited for dietetic and domestic use, for boilers, for chemical purposes, &c.* At a more recent period MM. Boutron-Charlard and Henry state, "that it had lost nothing of its purity and other good qualities.†

I have annexed two analyses of this water by the above-mentioned chemists; the one made shortly after its first flowing in 1841; and the other in 1848. They show a close uniformity in the total quantity of residue left by the evaporation of a litre of the water, and in the absence, in this residue, of the sulphates and chlorides of lime and magnesia; but they differ essentially as to the respective quantities of the carbonates of those bases,—the carbonate of lime being three quarters and the carbonate of magnesia one half less in the second analysis than in the first.‡ The salts of potash, on the contrary, show a corresponding increase. (See p. 211).

* Annales de Chimie et de Physique, 3me Ser. Tom. I. p. 381.

† "Analyse chimique des eaux qui alimentent les Fontaines publiques de Paris," 1848.

‡ The difference is in fact rather greater; for MM. Boutron-Charlard and Henry calculate the carbonates as in the state of soluble bicarbonates, which increases the weights of those salts by about a third. In comparing their analyses with those of the other chemists it is necessary to bear this in mind.

This fine work was executed by M. Mulot, at a cost of 363,000 francs, including two sets of tubes and all expenses.*

At Elbœuf there are several Artesian wells varying in depth from 460 to 590 feet. As well as I can judge from the descriptions given of them, they seem generally to terminate in the Upper, and not in the Lower Greensand. In some of them the water rose 106 feet above the surface of the ground. The quantity is variable: in one case 300,000 litres per twenty-four hours, and another 500,000 litres, were obtained. M. Girardin, whose analysis of one of these waters, probably from the Upper Greensand strata, is annexed,† observes that "its limpidity is perfect; that it dissolves soap readily, and boils vegetables perfectly well." I give M. Girardin's statement of the quantity of saline matter in the water of an Artesian well at Rouen; but I do not know the particulars of the analysis, nor the stratum in which it ends. Some of the wells at Rouen reach the Oolitic series, from which a good supply of water is procured, but of a quality not so pure as that of the Cretaceous series.

At Tours a large portion of the water supply is derived from Artesian wells. The chalk is there from 200 to 300 feet thick, and, beneath it, is a series about 300 feet thick of alternating beds of sand, clays, and green sands, in which as many as eight water-levels have been found. By uniting these several sources, one of these wells furnished 4000 litres per minute. The water rose at first from 20 to 25 feet above the surface; but this rise is since reduced. M. Dujardin's analysis of this water, which he states to be very good and well aerated, is annexed, (p. 211.)‡

* The copper tubes were first used, and afterwards replaced with others of galvanized iron.

† Journal de Pharmacie, Tom. XXV. p. 636.

‡ M. Hericart de Thury, "Rapport, etc." 1831, p. 35. The analysis was made soon after the well was finished in 1830.

A few other Artesian wells carried through the chalk might be mentioned: I will however allude to but one more, which has been made at Calais within the last few years. From its proximity to England it is of great interest, especially as it presents conditions strikingly resembling those which would probably be found to exist at London, and may be viewed, although unsuccessful in furnishing a supply of water, as a criterion of the difficulty and expense greater than would attend such an undertaking here.*

The following is a section of this well.†

		FEET.
Sands, gravel, and shelly sands,—recent		80
Lower part of the *Tertiary strata*, consisting of beds of clay, greenish sands, and pebbles		161
Upper chalk	300	762
Lower chalk	462	
Hard chalk with green particles		3
Dark bluish grey clay		26
Hard compact green sandstone (16 feet), and clays .		66
Calcareous beds—particulars not given, ending with the shales and sandstones of the *coal measures*. . .		40
		1,138

No water rising, the work was abandoned.‡

The bore was begun in 1842, and carried to a depth of 1,047 feet in the course of the first year and a half. It would have occupied less time, had it not been for delays in the arrival of the necessary apparatus. The large size and number of the round flint pebbles in the Tertiary strata, and the hardness of some of the beds of the chalk, also much retarded the work. The total expense, up to this time, amounted to 48,500 francs, apart from the cost of the

* From a cursory examination of the geology of that district, I believe that this failure is owing to a line fault of considerable magnitude passing between Calais and Sangate, and running in an east-south-east direction towards St. Omer.

† Almanach de Calais, 1845. Specimens of the strata are preserved in the Museum of that town.

‡ In the chalk itself a very trifling quantity of water was found at the depth of 95 and 260 metres; but it did not rise to the surface, and produced only 80 litres per minute at the utmost. The first pumpings were always brackish.

temporary tubes which came to 18,471 francs more. Had the work been successful, the engineer, M. Mulot, would have been entitled to these tubes together with an addition of 10,000 francs; consequently the expense of the work, necessary to have obtained the hoped-for supply of water at this depth, would not have exceeded 3,100*l*. A further sum of 12,000 francs was afterwards voted, and the works were carried, still without success, down to 1,150 feet—a depth, I believe, more than sufficient to reach the Lower Greensand at London—at a total expense of 3,600*l*.

As a measure of comparison with the Artesian well waters, I have, in the table, p. 211, given the analysis of the waters of the Seine and the Marne, taken near the junction of these rivers at a short distance above Paris. The water of the Seine, supplying the water works at Paris and taken from it at different places in its course through the city, gives upon analysis an intermediate amount of solid residue. A number of other smaller sources contribute also to the supply of Paris. The water of none of them is so good as that of the Seine itself at Ivry, and the greater number do not equal the water of the Marne. For further particulars of these waters see the work before quoted of MM. Boutron-Charlard and Henry.

M. Girardin observes of the Artesian well waters of France, "Après les eaux de pluie, les *eaux des puits Artésiens ou jaillissans* sont les plus pures; elles sont généralement abondantes, et moins riches en sels que les eaux des rivières et des sources."*

Artesian well waters, besides being employed for domestic uses, have been applied in France to a number of economical purposes, as for moving power for mills, factories, and hydraulic machines,—for warming large buildings, for public

* "Leçons de Chimie élémentaire appliquées aux Arts Industriels," vol. i. p. 59 Paris, 1846.

wash-sheds, for irrigation on a large scale, for fish-ponds, —in plantations of water cresses, paper-making, and the weathering of flax. The uniform temperature and limpidity of such waters render them of considerable advantage for many of these objects.

For other particulars in reference to Artesian wells in France, and for the discussion of the question generally, I would refer the reader to the works of M. Hericart de Thury, (see p. 10), to the scientific notice of M. Arago in the "Annuaire du Bureau des Longitudes" for 1835, "Sur les puits forés, connus sous le nom de puits Artésiens, de fontaines Artésiennes, ou de fontaines jaillissantes;" and to the excellent practical work of M. Degousée,—the "Guide du Sondeur."

Table of analyses of the waters of some Artesian wells in France, and of the Seine and the Marne above Paris, showing the quantity of saline matter (in grammes) in a litre* of water.

1 litre = 0·2201 gallon. 1 gramme = 15·428 grains.

	Artesian wells, deriving their supplies from the Greensand Series.					Artesian well in the Lower Tertiary Sands. Paris.[e]	Rivers.	
	Grenelle, Paris. 1841.[a]	Grenelle, Paris. 1848.[b]	Tours.[c]	Elbœuf.[d]	Rouen.[d]		The Seine at Ivry, near Paris.[f]	The Marne at Charenton, near Paris.[f]
	litres.	litres.	litres.				litres.	litres.
Atmospheric air†	0·0165	In quant. undetermined.	Quan. undetermined.	..		..	0·0130	0·013 0
Free carbonic acid	0·0015			..		..	0·0030	Qu. undet.
	grammes.	grammes.	grammes.	grammes.		grammes.	grammes.	grammes.
Carbonate of lime	0·0680	0·0292	0·2800	0·1633		0·4140	0·1320	0·3010
" magnesia	0·0142	0·0092	..	0·0800		..	0·0600	0·1200
Bi-carbonate potash	0·0296	0·0100	..	..		..	..	..
Sulphate of lime	..	..	0·0004	0·2629		0·0740	0·0200	0·0220
" magnesia	..	..	..	0·0676		..	0·0100	0·0180
" soda	..	0·0320	0·0016	..	Particulars not given.	..		
" potash	0·0120		..	..		..	..	..
Chloride of sodium	..	..	0·0336	0·0842		..	0·0100	0·0200
" magnesium	..	..	..	0·0120		..		
" calcium	..	..	..	..		0·0400		
" potassium	0·0109	0·0570	..	..		..	..	..
Silica, alumina, and oxide of iron	0·0059	0·0120	0·0044	0·0400		..	0·0080	0·0300
Alkaline nitrates	..	..	..	..		..	indications	traces
Organic matter	0·0024	traces.	..	traces		0·0120	traces	traces
	0·1430	0·1494	0·3200	0·7100	0·1327	0·5400	0·2400	0·5110

[a] Payen. [b] Boutron-Charlard et Henry. [c] Dujardin. [d] Girardin. [e] Payen, communicated by M. Degousée. [f] Boutron-Chalard and Henry.

* This analysis is repeated in English measures in p. 224, that it may serve to connect the two lists — as the French weights and measures are retained here.

† In the above analyses of MM. Boutron-Challard and Henry the lime and magnesia being considered as bicarbonates, about one third of their weight should be deducted in comparing them with those in the other analyses.

APPENDIX B.

On Springs arising from Faults, and their Analogy to Artesian wells.

WE have had occasion in the body of this work to discuss the theory of springs in those sedimentary formations, where the strata consist of loose permeable sands, as well as in one in which they are more solid and compact, and transmit water by percolation through fissures. In both these cases the question was considered on the supposition that the strata were undisturbed by faults; but if this element be introduced, the question becomes more intricate. These three conditions of the strata embrace almost all the phenomena presented by ordinary, as well as by thermal springs;—those owing to volcanic agency, and in some igneous rocks, excepted.

This third condition may be considered under two heads, accordingly as the fault affects loose and arenaceous, or solid and compact, strata.

1. To continue the illustration by referring to strata with which we are acquainted, and confining our attention to a single fracture only,* let a line of fault, attended with a difference of level on either side of the fracture of 100 feet, be presumed to run through the centre of the Tertiary district. As this gives a depth exceeding the average thickness of the Lower Tertiary sands, their continuity would necessarily be completely interrupted by such an amount of disturbance (see

* In disturbed districts faults are generally very numerous, and then the question becomes complicated accordingly. For a practical illustration of the difficulties attendant upon such a case I would refer to the valuable Report of Mr. Robert Stephenson on the supply of water to Liverpool, March, 1850.

fig. 16, p. 52). Supposing now that the portion of this deposit (*b*), to the right of the figure, reaches the surface at a distance of a few miles from the fault and at a higher level than the ground at this spot, the consequence will be that the water received at the outcrop of the sands, *b*, will penetrate as far as the line of fault and there be stopped or dammed back by coming into contact with the impermeable strata of the London clay, *a*.

A line of fault is one of forcible fracture, and the edges of the disjointed strata must have formed uneven and jagged surfaces, varying according to the texture and hardness of the beds and the lithological character of the different formations which the fault traverses; and as these truncated surfaces are shifted out of their true position, they necessarily will not fit one to the other. If the movement were merely one of vertical displacement, irregular spaces would be left between the walls of the faults, varying in proportion to the roughness of the broken surfaces. But these disturbances exhibit also the powerful efforts of solid masses, such as portions of the crust of the earth, to adapt themselves to smaller horizontal areas, and consequently the strata have either been bent into flexures and anticlinal ridges, or have been fractured and tilted into a variety of new positions at different levels, accompanied by very great lateral pressure;—the extreme force, with which the fractured edges of the strata have been moved one against the other reducing the irregularities of surface and keeping the separate portions of the disjointed strata close together, while the portions rubbed off by the friction at one part have served to fill up the intervals at another. In soft strata of clays and sands this operation generally closes altogether the seam of the fault, and therefore the superincumbent clays (*a*, fig. 16), remain as impermeable as if they had not been fractured.

2. But if the strata, *a*, should be hard and compact, then,

notwithstanding the great friction and lateral pressure, the irregularities of the fractured surfaces are such, that crevices may remain in the joining of the fault; and when that is the case, if the water-bearing strata, *b*, crop out at a level above that of the surface of the ground at the fault, then the water will tend to rise upwards through these crevices and issue at the surface, giving rise to springs proportionate to the dimensions of the water-bearing strata, the height of their outcrop above the level of the spring, and the size of the channels through which the water has to pass. But it is not necessary that *b* should be an arenaceous deposit; it may consist of compact beds, providing that water can percolate through them by joints, bedding, and fissures—only that the supply will be less. Nor need it indispensably be overlaid by impermeable strata; for if, by the operation of a fault, the fissures and planes of stratification are brought to abut against compact and unfissured portions of the deposit, the further passage of the water is stopped, unless, as in the previous case, it meets with crevices between the walls of the fault through which it can ascend.* This occurs occasionally in the chalk, and more frequently in some other formations. A small fault is often sufficient to produce such a result.

This phenomenon, therefore, evidently effects by natural operations that which artificially is obtained by means of Artesian wells.

* These springs are most common when the rocks are very hard, and the fractures comparatively recent. They probably would be of much more frequent occurrence, were it not that the older formations being overlaid to so great an extent by others of later date, the fractures, which existed anteriorly in the former, are covered and closed by impermeable masses of the latter. Even when the fractures extend to the present surface, these springs are far from being so numerous as the multiplicity of faults might lead us to expect.

This effective pressure, and water-tight condition of the edges of the fractured strata is, I conceive, one of the most decided proofs we have that the disturbances of the crust of the earth took place under very great lateral compression; for this strong hydrostatic test could scarcely fail to indicate the presence, in all formations containing water-bearing strata, of vertical fissures and crevices if they were at all numerous.

In the foregoing cases it is assumed that no communication for the water exists between opposite sides of a fault; either that the disjointed edges are, one or the other, impermeable, or that the smoothened surface of the walls of the fault, or else the debris which have filled their interstices, form an impenetrable barrier.*

But cases may occur, although they are probably rare, where the walls of the fault being in close contact, a passage of water may take place from one permeable deposit to another of a different age, but placed by the disturbance on the same level. This is likely to happen especially when a series of sandy strata are brought into juxtaposition with harder rocks, whose rough edges may project into the softer sands or sandstones; or when the difference of hydrostatic pressure is considerable. In this case the water from the water-bearing strata on the one side, would tend to force itself into the fissures and joints of the other truncated deposit, and through them to rise to the surface within the area of the latter.†

Now, as these faults are prolonged indefinitely downwards, the continuity of the water-bearing strata may be broken at any depth, and from that depth the water may rise to the surface. But the temperature of the crust of the earth is found to increase, in descending from the surface, at the rate of about one degree for every 50 to 60 feet, consequently the degree of heat of these springs will vary according to the depth which the water-bearing strata have reached at the point where they are intersected by the fault.‡

* The fault in fact very generally presents a mass of clay more or less thick, whatever may be the lithological character of the beds more immediately affected.

† May not the Bath and Cheltenham springs possibly be referable to some such causes. See Sir Roderick Murchison's "Geology of the neighbourhood of Cheltenham."

‡ The occurrence of thermal and cold springs along lines of *fault* is a fact which has long been established. In this country the hot springs at Clifton near Bristol, and at Matlock are examples of this phenomenon, both issuing on lines of disturbance and fracture easily observable. See the important paper on this subject by Prof. J. Forbes in the Phil. Trans. for 1836.

These causes appear to be sufficient to account for the phenomena presented by most cold and many thermal springs, without having recourse, unless in exceptional cases, to the volcanic or chemical theories. The steadiness of the supply and the uniformity in the temperature and contents of the water, indicate the magnitude of the subterranean reservoir and the constant regularity of flow in the same channels.*

APPENDIX C.

On the Waters of the Lower Tertiary Sands and of the Chalk beneath London.

VERY few separate analyses have been made of the waters from the sands between the London clay and the chalk, and many of these are from sources which render it difficult to certify to their exact stratigraphical position.† There appears also to be a strong probability that some communication, either natural or artificial, exists between these two waters. Some writers have considered that the chalk supplies water to the deep sand-springs, whilst others, on the contrary, are of opinion that the sands supply the chalk. At a

* From the foregoing observations it will be perceived however that the operation of faults is usually to interfere with and stop the underground flow of water. Were it not for this provision of nature, mining, in many instances, would be impracticable: —it would especially be the case in the *coal measures*, which are composed of so great a number of alternating strata, a large proportion of which consist of partially permeable sandstones. The faults in them are generally so numerous that the continuity of the strata is constantly broken; and the water which would otherwise have a wide and uninterrupted flow, is thereby restricted to separate and manageable sections. See Sir Henry De la Beche's "Geological Manual," 3rd Edit. pp. 12 and 379.

† In the case, however, of the Kentish Town well-waters very great care was taken to obtain distinctly the waters of each deposit. They were drawn from the separate strata at the respective depths mentioned in the analyses (p. 224.)

distance of a few miles from London the waters from these two deposits appear to be more distinct, and have each a separate character sufficiently apparent even without the aid of analysis: but at London the few that have been analysed show a chemical composition very nearly alike. Professor Brande observes, however, that in most cases the water from the Lower Tertiary sands is not so pure as that from the chalk.

The *Lower Tertiary sands* are in the main siliceous, although carbonate of lime is frequently present in not inconsiderable quantities. They contain subordinate beds of clays sometimes carbonaceous and pyritical,—layers of fossil shells,—the green silicate of iron in dispersed grains,—and occasional crystals of sulphate of lime; consequently the water from this source, although generally good, cannot be always depended upon, it being occasionally slightly chalybeate,—sometimes not to such an extent as to be perceptible to the taste, or to be unfit for domestic use,—at other times so much so as to render it unusable for any purposes.* But the springs usually tend to improve by use.

The decomposition of the iron pyrites (sulphuret of iron) by the joint action of the vegetable matter, and the water in the same beds, sets free not only the salts of iron, but also gives rise apparentlyto the evolution of sulphuretted hydrogen.

In sinking wells this gas is sometimes met with, especially in wet and rainy weather. The quantity generally evolved is extremely small, and hardly perceptible when the flow of water is constant, but after being shut off for a few hours, the water, when first drawn, is sometimes perceptibly impregnated with it. This is more particularly apparent in some of the wells in the valley of the Lea. Exposure to the atmosphere for a few hours removes this impurity.

* This is more particularly the case with the lesser springs in the bed of sand and conglomerate immediately at the base of the London clay.

At Waltham Abbey the water from these sands is used to a considerable extent, and is reported to be very good. The same at Water Lane, Edmonton.

At Merton this water is preferred to that of the Wandle. At Tooting and Garret it is generally liked.

Annexed (p. 224) are the particulars of a recent analysis, by Mr. R. Warington, of the waters from the Lower Tertiary sand and from the chalk in the same well at Kentish-town. They show a singular agreement, but one which would, I think, rather indicate a transfer of a portion of water from the sands to the chalk, than from the chalk to the sands.

In many wells, when first constructed, the water from these sands is very impure, but this must not be considered as a criterion of their quality, for it is found that after the well has been in use for a few months the water almost invariably improves. The defects arise from local causes, and are, I believe, more particularly to be attributed to the variety of mineral character introduced into the Lower Tertiary in the neighbourhood of London, by the setting in of the fluviatile beds so conspicuous at Woolwich and Lewisham.*

The Chalk.—The waters from this formation have been more frequently examined than any others. The quantity of

* Mr. R. Mylne informs me as the result of his experience that,—"The water from the sands below the London Clay is generally both soft and wholesome, but instances sometimes occur to the contrary in new wells, particularly in the southern districts; the water when first drawn being occasionally charged with impurities, impregnated with iron, and unfit for domestic use. Under these circumstances either by continuous pumping, or after a lengthened use, a progressive improvement in the quality of the water invariably takes place.

"As the strata are known to differ considerably in their mineral structure, it is probable that the quantity of salts which they contain vary in different localities; and consequently any excess of these soluble products at particular points might give rise to these exceptional cases. By the constant action of purer waters flowing from more distant points the objectionable ingredients are thus rendered less apparent and gradually pass off in solution.

"In one district a few miles north of London the water obtained from the sands by any new boring usually contain a strong odour, with a peculiarly disagreeable taste which continues for two or more months, when the water at length attains its proper condition.

saline matter held in solution varies very considerably accordingly as the water is from the springs and streams on the surface, or from Artesian wells.

In the former the water generally contains about 18 to 22 grains per gallon of solid residue, of which from 15 to 20 consist of carbonate of lime, 1 to 2 of chloride of sodium (common salt), 1 to 2 of sulphate of lime, and traces of a few other substances. These proportions are tolerably constant. The change exhibited in the water from the chalk beneath London is remarkable. The solid residue has increased on the average to about 55 grains per gallon, in which the carbonate of lime is present to the extent only of 1 to 7 grains; whilst there appears 12 to 18 grains of carbonate of soda or potash, together with 5 to 20 grains of the sulphates of the same bases, and 10 to 20 grains of chloride of sodium.

Notwithstanding, however, the increase in the total amount of the salts, the presence of alkaline carbonates, and the decrease in the quantity of the salts of lime, render the water soft and generally good for many domestic purposes.

Various reasons have been assigned to account for the large quantity of common salt contained in the chalk water beneath London. It has been suggested that, owing to the exhaustion which has taken place in the wells, there is now an influx of the brackish waters of the Thames through the fissures of the chalk at its outcrop between Woolwich and Gravesend. It, however, need not necessarily arise from this cause. The quantity of chloride of sodium in the water also by no means increases in proportion as we ap-

"The fact of water being temporarily surcharged with the products of the strata through which they pass is often exemplified in the springs of the extensive gravel deposits resting on the London clay. A disturbance of the ground from the construction of sewers and other similar works occasionally intercepts some of the subterranean channels communicating to the wells, and the water, consequently drawn from a new direction, is liable to become largely charged with sulphates of lime and other mineral and earthy salts, rendering it for a considerable period bitter to the taste, and wholly unfit for general purposes."

proach that outcrop of the chalk.* This salt is commonly, or rather almost constantly, present in all sedimentary rocks. Some recent experiments of M. Maumené have shown that it exists in as large a proportion in the wells of Rheims, (a city which is situated in the midst of an extensive chalk plain, 300 feet above the level of the sea, and 140 miles distant from it), as in the wells at London. He gives several analyses in which the quantity varies from 15 to 22 grains per gallon.

It is possible that this salt may have been left in the chalk by the ancient ocean in which that great deposit was formed. We know it by its organic remains to be of marine origin. The fine texture of the mass and its strong capillary attraction, would render the drainage from it—after elevation into dry land—of the water with which it must have originally been saturated, a work of a very great length of time. But during the ages since its actual surface has been exposed to the action of rain water, the upper beds have been so washed that comparatively little of the chloride of sodium remains in them. But where the beds are very deep seated, and more especially when covered and protected by Tertiary strata, then although they may have been in a state of constant saturation, there has not been a sufficient flow and change in the water to effect the removal of the salt originally left in them.

Another objection against any general infiltration of the Thames water, is the great variation which exists in the proportion of the saline ingredients in all the deep well waters that have been analysed. No two are alike. The quantity varies from 33 to 70 grains per gallon. This no doubt arises from the different levels to which almost all the wells are sunk, for the chalk varying slightly in its composition from

* In two Artesian wells near the river at Greenwich, the waters of which were analysed by Prof. Graham, the chloride of sodium was present only to the extent of 0·37 and 3·12 grains per gallon.

the lower to the upper beds, and the water passing chiefly along the planes of stratification, the mineral matter which it takes up is likely to vary according to the different portions of the formation with which it comes into contact. If the waters were derived from the Thames, it is probable that their saline ingredients would show less variation, although the same lithological cause of differences would still of course continue to operate, but it would cause an addition to a constant quantity that would scarcely allow of the extent of variation which now exists. The difference in general chemical composition of these waters would also be difficult to reconcile.

In support of the infiltration of the river water, it has been shown that some of the deep wells in and around London are influenced by the tide to the extent of as much as from 2 to 4 feet, whence it has been inferred that there are communicating channels between the river and the subterranean strata, through which the water finds a passage.

But this is a phenomenon common in water-bearing strata, particularly in those which are compact and in which water is transmitted through fissures, both near tidal rivers and near the sea. It is of frequent occurrence on our own coasts; and is exhibited sometimes in the chalk plains of Picardy to a distance of several miles from the sea. Many of the wells round Abbeville are affected by the tide.* The varying pressure exercised by the sea at high and low tide has been found to

* A curious case occurs at Noyelle-sur-mer (Somme).[1] Some meadows required a supply of fresh water for the cattle. An Artesian well was sunk to a depth of 55 feet in the chalk. A supply of water was obtained rising at high tide just to the surface of the ground, but lowering 6 feet as the tide fell. A large pond was therefore excavated at the top of the well, and now the water, which is perfectly fresh and good, is forced in by the rise of the tide; the orifice of the bore is then closed by a valve, and the fall of the water back into the subterranean reservoirs, as the tide retreats, is thereby prevented. A large and fresh supply of water is thus forced or pumped up at each successive tide by these natural and most effective means.

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[1] Baillet, "Bulletin Soc. d'Encouragement pour l'Industrie Nationale, 1822.

be perceptible as far inland even as Lille, where there is no tidal river, and which is at a distance of forty miles from the sea.* It is evident that there are communicating fissures, in the one case with the Thames, and in the other with the sea, but they are fissures of discharge and not of reception.† They are the vents by which the waters, held in the strata above those levels, escape; as the column of water in the river or sea over these openings increases with the tide in height and weight, so does the increased pressure, which is thus exercised, retard or stop the flow of water from them; or may even cause a reflux in the fissures of the rock, in which the water will tend therefore to accumulate and rise, until the pressure is removed again by the fall of the tide.‡

With regard to the other salts present in deep well waters, the mineralogical composition of the chalk affords an easier clue to the origin of most of them. The upper part of the chalk consists almost entirely of pure carbonate of lime. In descending, however, the strata become more and more argillaceous, until, on reaching the chalk marl, a very considerable per centage of clay is found mixed with the chalk. Iron pyrites is also disseminated in the chalk with flints, but in yet greater abundance in the chalk without flints forming the lower division of this formation. The hydrated per-

* On some days the fluctuation was found to amount to about 17 inches, and on others, only to 1 inch. The greatest height of the water was always about eight hours after high tide at Dunkirk. The maximum yield of water under these circumstances was 63½ litres per minute, and the minimum 35 litres. This is so remarkable a case that the "Académie des Sciences" obtained the report of a Government Engineer upon it. All the changes during a period of five weeks were very carefully noted.—"Rapport" by M. Bailly, Comptes Rendus. T. 14. p. 310, 1842.

† It must be admitted, however, that at London, where the exhaustion by pumping is now so great, as the sand and chalk which supply the deep well water crop out at so short a distance down the river, such an infiltration is possible. Should it however occur, it appears to me, upon geological grounds, that the water is more likely to pass into the chalk beneath London, indirectly by the medium of the overlying sands, than directly from the outcrop of the chalk itself below Greenwich. This view would avoid some of the difficulties I have alluded to.

‡ See also note, p. 193.

oxide of iron occurs in small quantities throughout the chalk. Fragments of wood are also found dispersed, although in small and rare fragments. The exuviæ of animals (coprolites), which are occasionally found in the chalk, contain phosphate of lime. These substances are all sufficiently apparent, and constantly come under the notice of the geologist.

It remains to be determined by future investigation,—whether, according to a suggestion of Prof. Playfair, the alkaline carbonates owe their origin to the presence of decomposable alkaline silicates, which, by their affinity for free carbonic acid, abstract that holding the carbonate of lime in solution, which is therefore precipitated, and alkaline carbonates formed; or whether, according to the views of Berthollet, the reciprocal action of a dilute solution of chloride of sodium in intimate and long continued contact with carbonate of lime, under certain conditions of pressure and temperature, is such as to produce their mutual decomposition.

With regard to some portion, however, of the saline ingredients found in the waters of the chalk beneath London, I believe that they often owe their origin to an infiltration (not general but in places) of water from the more varied mineral mass of Lower Tertiary sands so immediately overlying this formation.

In the table, p. 224, I have given some of the most recent analyses of the waters of the London district. They present a fair average of their general character. Appended to this list is the analysis of the water of the Artesian well of Grenelle.

In addition to the fuller particulars given in the table, is the annexed list of some more general results, showing merely the total quantity of solid residue in other river and Artesian well waters at and near London.*

* Chiefly from analyses by Prof. Brande and Mr. Warington.

List of some of the principal Analyses of the River and Well Waters used in London, showing the Quantity in Grains of solid Residue in an Imperial Gallon of Water.

	Artesian Wells terminating in the Chalk.				Wat. taken at 170 feet below the top surface of the chalk.	Water from the sands immediately above the chalk.	River Water.				Spring water at the outcrop of the Chalk.		Artesian well ending in the Lower Green-sand.
	Long Acre.[a]	Trafalgar Sq. Wells.[b]	Ratcliff.[c]	The Mint.[d]	Hampstead Water Works Compy's. well. Kentish Town.[e]		Thames at Twickenham.[f]	Thames at Greenwich.[g]	River Lea at Tottenham.[e]	River Colne.[h]	Chadwell spring, Ware.[e]	Bushy Meads Watford.[i]	Grenelle, Paris.[j b]
Carbonate of lime	6·1800	3·2550	7·2238	3·5000	4·2600	0·3000	12·7595	14·39971	3·0000	18·1000	13·5000	17·0000	4·7600
" magnesia	1·0800	2·2540	2·1741	1·5000	..	..	1·0271	..	..	..	..	0·4300	0·9940
" soda	11·6800	18·0488	6·2802	8·6300	14·3200	16·3200	..	..	..	..	..	..	..
" iron	..	..	0·1941	..	..	..	traces	..	..	..	..	..	..
Bicarbonate of potash	..	..	..	..	..	..	..	..	..	..	..	..	2·0720
Sulphate of lime	..	..	..	..	..	..	0·4507	..	0·2500	1·2000	1·2000	1·2000	..
" potash	..	13·6710	1·2621	..	..	..	0·6679	1·3710	..	..	..	..	0·8600
" soda	24·2500	8·7493	6·4997	13·1400	13·0000	15·5000	2·0001	3·9224	..	..	..	..	..
" magnesia	..	..	..	..	..	..	..	0.5475	.	..	..	..	..
Chloride of calcium	..	..	..	..	..	..	1·7502	..	..	..	..	..	..
" potassium	..	..	..	..	..	..	..	1·6272	..	..	..	traces	0·7630
" sodium	12·7400	20·0585	10·0575	10·5300	17·2200	11·5000	..	..	1·8500	2·0000	2·5000	1·8200	..
" magnesium	..	..	..	..	..	..	.	1·1482	..	..	..	..	..
Phosphate of lime	0·1900	0·0340	..	..	..	..	..	..	..	..	..	traces	..
" soda	..	0·2910	..	..	..	..	..	..	..	..	..	..	..
" iron	0·2400	..	..	traces	..	..	..	traces	..	..	..	..	..
Silica	0·4400	0·9710	1·1461	0·5000	1·4000	1·5000	0·2731	0·7958	0·5000	traces	0·4000	1·1400	0·3990
Alumina	..	..	..	..	..	..	traces	..	..	..	..	..	..
Phosphoric acid	..	..	..	..	..	..	traces	..	..	..	..	..	..
Apocrenic acid	..	0·0987	..	..	..	..	..	..	..	..	..	..	..
Crenic acid	..	0·1372	..	..	..	..	..	..	..	..	..	..	..
Extractive matter	..	0·6720	..	..	..	..	..	..	..	..	..	..	..
Organic matter & wat. of com.	..	..	0·5740	traces	2·5000	1·0800	2·2854	..	1·4000	..	0·4000	..	0·0152
Insoluble organic matter	..	..	..	..	..	..	1·1948	4.0810	..	..	..	..	..
	56·8000	68·2405	35·4116	37·8000	52·7000	46·2000	22·4088	27·8928	17·0000	21·3000	18·0000	21·5900	9·8632

[a] Graham, Mem. Chem. Soc. Vol. II. p. 39. [b] Abel and Rowney, Quart. Journ. Chem. Soc. Vol. I. p. 97. [c] Mitchell, Quart. Journ. Chem. Soc. Vol. III. p. 32.

River Waters.

	Grains per Gall.
Thames at Teddington	17·4
„ at Westminster	24·4
„ at London	28·0
River Lea, Ware	22·0
River Mimram, Hertford	20·5
New River	19·2
River Ravensbourne at Deptford	20·0

Artesian Wells in the Chalk.

Belvedere Road, Lambeth	50·0
Berkeley Square	60·0
Hampstead Road	49·3
Trafalgar Square, (Brande)	68·9
Camden Town	44·0
Greenwich Hospital	27·30

The proportion of saline ingredients in the waters of these two sources affords no criterion of their relative hardness. In fact, from the large preponderance of alkaline salts, the Artesian well water is soft, averaging about from 4° to 6° by Dr. Clark's standard, whilst the hardness of river and of the superficial chalk water, ranges from about 12° to 20°. The hardness of the shallow well water is very much greater than either of the above, reaching to as much as 40° and 60°, or sometimes more.

The temperature of the Artesian well waters varies, according to the depth of the well, from about 54° to 62° (being very commonly about 58°); but it is constant at each well.

While upon this subject I also add a list of the total quantity of solid residue found in some of the shallow land springs of London.* They afford a fair criterion of the large amount of saline ingredients usually existing in the gravel springs. In appearance these waters are perfectly bright and limpid, and many of them are in much repute as good drinking waters. They have certainly suffered from the construction of sewers, the laying of gas-pipes, and numerous other causes of impurity; but it is a matter of surprise that the injury should not have been greater. There seems to exist in the common ochreous gravel of London some remarkable

* The earliest analysis of the shallow well waters appears to have been made by Cavendish in 1766. An account of it will be found in the Phil. Trans. of that date. It refers to the Rathbone Place spring, which was at that time raised by an engine to supply the neighbourhood. The per-centage of solid residue is large (17·5 grains in 7315) and in the main correctly distinguished—consisting chiefly of carbonate and sulphate of lime. See his Life in the works of the Cavendish Society.

properties, not only as a filtering material, but also as one which tends to rid the water of its organic impurities.

*Shallow Well and Pump Water.**

	Grains per Gall.
The Treasury	63·0
St. Paul's Churchyard	75·0
Postern Row	88·0
St. Martins'	95·0
Belvedere Road, Lambeth	110·0
Old Street, St. Luke's	110·0
St. Giles	105·0
Bream's Buildings	115·0

APPENDIX D.

On the Relation of the Geological Changes,—accompanying the formation, and determining the Lithological Character, of the Sedimentary Deposits,—with the present condition of the Waters in their Water-bearing Strata.

In considering this question it will be sufficient for our purpose if we divide rocks into—1. those of igneous origin, or subsequently modified by igneous action, and — 2. unaltered deposits of sedimentary origin. As a broad line of distinction, the first exhibit chemical phenomena in which atmospheric agents have not necessarily had a part; whereas the second, having been formed from the degradation of previously

* These particulars are taken from a paper by Prof. Brande, in the Quart. Journ. Chem. Soc. Vol. II. p. 435, 1850,—except that of the Treasury Pump, which is by Dr. Bostock, 1834. The residue of this last consisted of carb. lime, 34·3, sulph. lime, 16·1, and chlor. sodium, 12·6 grains per gallon. The valuable series of experiments recently performed by Prof. Brande and Mr. Warington, for Mr. Rennie, and contained in his "Report on the supply of water to be obtained from the district of Bagshot," 1850, affords much information on the subject of the composition of the waters of the stream and wells of the chalk, as also of the streams of a portion of the Bagshot district.

existing lands, were inevitably exposed during their progress to the full effect of those agencies. With the former the changes generally had a tendency to deoxidise, and with the latter to oxidise, the masses affected; and consequently we have chemical products of very different affinities and degrees of solubility in those two classes of formations.

A large portion of the rocks of igneous origin consist of silica, partly pure, and partly combined with earths and alkalies. In the first case they are insoluble, but in the latter they often form mineral masses, which are slowly decomposed by water holding carbonic acid in solution, and they then produce soluble alkaline carbonates, and insoluble residuary earthy silicates.

The older rocks of sedimentary origin, or even those more recent ones which have been modified by heat, are composed of strata frequently resembling in parts very closely some of the igneous rocks in their general character; but their lithological structure is less varied and crystalline, and presents fewer portions affected by atmospheric influences.

With respect to the nature of the saline ingredients set free by these rocks, it is to be observed that the purer alkaline silicates consist of silica in combination with alumina on the one side, and with potash generally, and soda occasionally, on the other. Their decomposition by carbonic acid gives to the water the carbonates of potash and soda and traces of silica, leaving an insoluble silicate of alumina, which forms the basis of all clays. Other silicates are more complex, containing,—either instead of, or in addition to, the above named alkalies,—lime and magnesia, and sometimes iron, all of which may be liberated by the decomposition of the constituent minerals.

These elements, in different forms and with slight variations of chemical composition, compose the mass of all the first-mentioned class of rocks, and supply the bases, which, united to various acids (the muriatic, sulphuric, and carbonic

chiefly), form the great bulk of the soluble salts found in waters. Their degree of solubility varies, however, very greatly. *All the salts* of potash and soda are soluble,—a property possessed by no other base. Of the salts of lime, magnesia, and iron, some are soluble and others insoluble. In the latter category are their carbonates (their most common form), but when the water contains free carbonic acid, portions of these minerals are dissolved by it,—an ordinary cause of mineral impregnation.

In the thermal and mineral waters of crystalline and schistose rock districts, the above noticed minerals are of common occurrence; and others, not here mentioned, including various phosphates, fluates, &c., are found occasionally. The former, however, may be considered as constant, and the latter merely as exceptional ingredients.

The different regions formed by these rocks present striking contrasts with regard to their water-supply. Over large areas they consist of hard, massive, and comparatively indestructible siliceous rocks (quartz, rock crystal, and granite in part), and compound earthy silicates (schistose rocks or slates), over which water will flow almost as pure as it falls. In other tracts compound alkaline silicates (all varieties of felspathic rocks, granite in part, and almost all basaltic and trap rocks) and calcareous strata prevail. Some of these are as hard and durable as those of the preceding group; but others, on the contrary, disintegrate (often rapidly) by exposure to the atmosphere, and by the action of carbonic acid and oxygen in the surface waters.*

* The spring and river water in the granitic district of Aberdeen is stated to be amongst the purest in the kingdom, being very soft (one to two degrees of hardness) and containing very little solid residue; whereas the ordinary well water in the granite district of Kingstown, near Dublin, is very impure, containing, I am informed by Mr. R. Mylne, from a recent analysis of Mr. Warington, as much as 89 grains of solid residue per gallon, and showing 20° of hardness. Whether the proximity of the sea, or of the Limestone at Blackrock, may effect this result, is questionable. The Granite, however, contains decomposing minerals; and the water, standing in the wells, is more liable to contract impurities.

But in the case of the other sedimentary deposits the conditions are widely different. They are formed, it is true, from the debris of the older formations,—the siliceous rocks and minerals, and the veins of quartz in the schistose strata, furnishing quartz pebbles and quartzose sand,—the silicates of alumina decomposing into clays,—and the granites and porphyries into sands, grits, and clays. At the same time any lime present in the decomposing mineral masses abstracts the free carbonic acid from the water to form carbonate of lime, so conspicuous a substance in the sedimentary strata; whilst the more soluble alkaline salts remain in solution in the water, which effected the degradation of the mass, and the transport of the debris.*

The adjustment in the contents of the waters, which takes place with reference to the effects of these changes, is extremely beautiful. So long as the original rock masses were *in situ*, their waters possessed properties peculiar to each separate locality; and if the solvent power of water remained as great for the whole of those soluble salts taken together, as for each group separately, then there would be a probability that the strata, derived from the debris of these rocks,—presenting as they do a structure and composition fitted, from their more open texture, to facilitate the further action of water,—would tend rather to increase than to diminish the average quantity of mineral matter that might be held in solution. But in the first place the whole mass of the

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sedimentary strata having, in the course of transport as debris from the land to the sea, been, as it were, washed, all the salts immediately soluble must have been removed. The reconstructed mass would then in fact be formed of the most unalterable debris of the older rocks, and of those portions of them which undergo change slowly. Further, in any decomposition by aqueous agency which might afterwards take place in these newer rocks, the variety of minerals, brought together into the same deposit, generally not only effectually prevent, by their variable chemical affinities, any excessive saline concentration, but more often tend by their mutual reaction, and by forming insoluble precipitates, to free the water from its mineral impurities.

In the older rocks the springs derive their properties from some peculiarity of the particular bed or vein, through which the water passes before rising to the surface. Some hold metallic salts in solution, others alkaline, and some are acidulous. The sedimentary strata will necessarily include, indiscriminately in the same deposit, materials originating from these various sources. The debris of felspathic rocks, which are almost always, to a certain extent, decomposed by the action of the air and water, set free alkalies, alkaline earths, and alkaline carbonates, all of which react upon metallic salts, precipitating them generally as insoluble oxides, or sometimes as carbonates. These salts are also decomposed in the presence of alkaline sulphurets and almost all phosphates.

The muriates and sulphates of lime and magnesia are incompatible with the alkaline carbonates; * whilst carbonic acid precipitates lime and magnesia by converting them into insoluble carbonates, although a further quantity of this gas has the property of dissolving a portion of them again. Exposure to the air, even without the presence of reagents,

* To what extent they react one on the other when in a state of very great dilution in natural waters is however doubtful, see note p. 158.

converts several soluble salts into others which are insoluble. Thus, where the underground water contains an excess of carbonate of lime, it liberates, on reaching the surface, a portion of carbonic acid (the solvent of the carbonate of lime), and this mineral is precipitated. This is a well known phenomenon of common occurrence.

The sulphates of which the bases are very oxidizable absorb oxygen from the air, and are converted into insoluble sub-salts of the peroxides, and into super-salts, which remain in solution. The protosulphate of iron acts in this way. Under water, on the contrary, sulphates in a very diluted state, and in presence of organic substances, part with their oxygen, and are converted by slow degrees into sulphurets.

The object of the foregoing observations is to call attention to the leading fact, that in *arenaceous strata* produced by the destruction of older and crystalline rocks (whether directly or indirectly is immaterial), the whole of their component mineral matter has been *successively exposed to the action of air and water;* and consequently that the oxidizable portions must in greater part have been oxidized,—the soluble salts dissolved out,—and the incompatible salts decomposed,—before they were accumulated in their present position. As the waters, which served as a menstruum, retired, traces, merely, of the presence of these salts were left in the desiccated strata. Kuhlmann and Vogel have found salts of potash and soda in all sedimentary calcareous rocks; and the analyses of mineral waters, as well as of river and well waters, show that the chloride of sodium (common salt) is very generally present.

The quantity of these salts remaining in the strata will depend chiefly upon the capillary attraction of the mass, which is strongest in argillaceous and calcareous, and weakest in the arenaceous strata. In these latter, therefore, they may have been in great part washed out by subsequent infiltration of

water; although that will depend materially upon whether the formation has, as a whole, been elevated, subsequently to its consolidation, into such a position above the sea level as to admit of its drainage and of the subterranean passage through its mass of the water from its outcropping surface. I do not now take into consideration the occurrences of rock salt, gypsum, or any local deposit of mineral matter. These are particular occurrences arising from some specific cause. The present observations refer solely to general conditions. They are made to show a general principle tending to counteract the solvent power of water, and to maintain the great mass of subterranean waters in a state of comparative purity,—and are not intended as a sufficient explanation of the occasional and interesting local causes which give rise to unusual saline states of the waters, and to mineral springs.*

Synchronously with the accumulation of some of the older sedimentary strata, we find traces of the commencement of organic life. This introduces an important element in the chemical changes which took place in these rocks; for as animal and vegetable matter became widely spread, it could not fail frequently to affect and modify the chemical nature of the deposits; particularly if, as there appears every reason to believe, the temperature of the surface was then considerably higher than it is now. The presence of animal and vegetable matter in a state of decay, either dispersed in accumulating strata, or else diffused in water, tends to deoxidize various minerals and salts. Under these conditions sulphuretted hydrogen and carbonic acid gases would be generated by the decomposition of the sulphates, and the latent combustion of carbonaceous substances: the peroxide

* For information on this subject I would particularly refer to the valuable Papers of Dr. Daubeny, in the Edinburgh New Philosophical Journal for 1831, and in the Transactions of the British Association for the Advancement of Science, for 1836: to Dr. Gairdner's treatise " On Mineral and Thermal Springs," Edinburgh, 1832: and to Prof. James Forbes's Paper in the Philosophical Transactions for 1836.

of iron would also be converted, first into the protoxide and then into the carbonate. The presence of vegetable matter would further affect the alkaline silicates, by supplying carbonic acid to their bases, whereby the silica would be precipitated, and alkaline carbonates disengaged. The effects of subterranean heat on rocks so composed, would likewise have to be considered.

This subject is one of too great an extent to allow me to do more than indicate thus generally its importance and interest, with reference to the influence of former geological changes upon the present condition of the waters in some of the permeable sedimentary deposits.

APPENDIX E.

On the Cost of some Artesian Wells in England and on the Continent, with reference to the probable expense of sinking Wells of this description into the Upper and Lower Greensands beneath London.

INTO this question, as matter of *exact* estimate, I am not competent to enter. But as some particular facts serving as a rough criterion of the probable cost of such works may be thought desirable, I have collected a sufficient number of cases to illustrate the actual expenditure that has been commonly incurred, and the great difference of cost between *shafted* and *bored* wells; and as data for some *general* calculations.

Owing to the water-level in the Artesian wells of London being at a depth of 40 to 60 feet below Trinity high-water

mark, it is, in almost all cases, found advisable, or necessary, to sink shafts to a short depth below that level, and then to bore either into the Tertiary sands, or into the chalk when the supply of water from the former is, as now frequently happens, deficient. This not only causes a considerable increase in the first cost, but it also necessitates a large outlay for engines; whilst the pumping up of the water becomes a not unimportant annual charge.

But, on the contrary, when the water rises above the surface, and boring alone suffices, the expense is comparatively light; it increases, however, very rapidly in proportion to the depth.*

The first part of the following list (1 to 3) serves to show generally the cost of the large deep wells in London; and it will not be found surprising that the expense has been considered a serious objection to their extension. Where a smaller supply of water is required, and the works consequently are not so heavy, or where the difficulties of the work have been less, a great reduction in the cost is apparent. (4).

The latter part (6 to 8) of the list exhibits the much more moderate cost of true Artesian wells, *i. e.*, wells in which the water overflows at the surface, and which therefore only require tubular bores. At Cambridge, although short shafts (12 to 15 feet deep) are necessary, the wells are so numerous that the expense of construction seems to be unusually small.

Now, as the waters from the Upper and Lower Greensands would probably rise everywhere above the surface at London, tubular bored wells would alone be required, without pumps or engines to bring up the water to that level. But the depth to which it would be necessary to bore much exceeds

* 10 feet can be bored for *5s.*; 40 feet *2l. 10s.*; 60 feet *5l. 5s.*; 100 feet *13l. 15s.*, and so on in proportion. The charges, however, vary, and are often less than this. But this shows the proportion generally, and points out the rapid ratio of increase.

that of any of the wells in or near London. We therefore have no evidence from actual experience in this country respecting the cost of such works,* and we must refer to those which have been constructed in France. Some of the data there furnished are peculiarly applicable, as we find wells traversing strata, considerable portions of which are of the same lithological character as those occurring beneath London.

Situation of Well.	Depth.			Cost.
	In Tertiary strata.	In chalk.	Total.	
	Feet.	Feet.	Feet.	£
[1]Truman, Hanbury, and Co.†	196	194	390	4,444
[2]Reid and Co.‡	136	123	259	7,700
[3]Blackwall Railway§	..	..	..	8,000
[4]Zoological Society, Regent's Park‖ ..	220	7	227	1,957
[4]Model Prison, Pentonville¶	220	150	370	1,600
[4]Lunatic Asylum, Colney Hatch** ..	188	141	329	1,273
[5]St. Mary Woolnoth, Lombard St.†† ..	252	0	252	200
[6]Water Lane, Edmonton††	66	0	66	13
[6]Waltham Abbey††	90	0	90	16
Wigborough, Essex††	300	0	300	abt. 120
[7]Loughton††	324	211	535	„ 750
[7]Mitcham‡‡	190	21	211	„ 100
[8]Cambridge§§	..	..	130 to 150	15 to 20

[1] A shaft sunk through the Tertiary strata, and a bore into the chalk.
[2] A shaft sunk the whole depth.
[3] No particulars given.
[4] Shafts sunk to base of the London clay, then bored the remaining depth.
[5] Bored the whole depth, just reaches the chalk.
[6] Bored the whole depth,—ending at the top of the lower sands overlying the chalk.
[7] Bored the whole depth through the London clay, Lower Tertiary sands, and into the chalk.
[8] Bores through the Gault to the top of the Lower Greensand.

* The Southampton and Chichester wells, though deep enough, do not meet the case.

† Davison, Proc. Inst. Civ. Eng. for 1842, p. 194. The additional cost for engine and pumps amounted to 1,351*l*.

‡ Braithwaite. "Includes the hire and repair of temporary pump, and the cost of two new sets of permanent pumps." Proc. Inst. Civ. Eng. for 1843, p. 165.

§ Braithwaite, Report of the General Board of Health on the Water Supply, 1850. Evidence, Appendix No. II. p. 98.

‖ Zool. Soc. Reports, 1836; but since carried seven feet deeper. Includes cost of engine house and reservoir. ¶ Communicated by Dr. G. O. Rees.

** Report of Committee of Visitors, January, 1850. Includes cost of pumps.

†† Manuscripts of the late Dr. Mitchell. ‡‡ Mr. Nightingale. §§ Mr. Deck.

Situation of Well.	Depth.				Cost.
	In Tertiary strata.	In chalk.	In strata beneath the chalk.	Total.	
	Feet.	Feet.	Feet.	Feet.	£
Paris, abattoir de Grenelle*	148	1394	256[a]	1798	14,500†
Calais‡	241	762	135[a b]	1138	3,560
St. Fargeau, Dept[t]. Yonne§	..	120	546[a]	666	1,216
Lille, „ Nord§	25	200	367[b]	592	320
Crosne, „ Seine and Oise§	333	..	..	333	190
Brou, „ Marne§	246	..	..	246	200
Ardres, „ Nord§	132	22	..	155	64
Claye, „ Seine and Marne§	108	..	..	108	78
Chaville, „ Oise§	65	..	..	65	15
Donchery, „ Ardennes§	..	..	..	1215	3,045
Kissengen, Bavaria‖	..	..	1878[c]	1878	6,666

[a] Greensand and gault. [b] Carboniferous series.
[c] Bored the whole depth through the New Red Sandstone.

M. Degousée has recently informed me of his having contracted to bore an Artesian well at Rouen to the depth of 1080 feet (through the Lower Cretaceous and Oolitic series) for 1,600*l.*,—expenses of every description to be defrayed by him. This he states he is enabled to do in consequence of using some new machinery, and by the application of steam power.

M. Degousée has also constructed three Artesian wells in different parts of France to a depth of about 820 to 830 feet each, at an expense, including tubes and all expenses, of from 600*l.* to 1,000*l.* The Calais well offers a very near counterpart of the deposits which occur beneath London, but the difficulties of the first 240 feet much exceeded those which would be met with here, and the Chalk is probably 100 to 200 feet thicker. There and at Paris, the first 1,000 feet cost less than 3,000*l.*, and at Donchery apparently not much more than 2000*l.*

* Communicated by M. Mulot, the engineer of the work, who states however that a similar work could now be executed for 10,000*l.*

† This includes two sets of tubes and the constructions over the well. There were a number of extra expenses attending this work, arising from the novelty of the undertaking. The contract for the first 1312 feet was 4,000*l.*

‡ Report of M. Legros-Devot, mayor of Calais. This well was first carried down to a depth of 1047 feet for 3100*l.*, or rather for that sum less 10,000 francs, to which M. Mulot would have been entitled, had the work been successful. The tubes were only temporary. The Tertiary strata presented considerable difficulties.

§ Degousée, "Guide du Sondeur." M. Degousée also mentions that the sixteen Artesian wells which he constructed at and near Tours cost together 5,872*l.*, the average depth being nearly 500 feet. They traverse the chalk and part of the Greensand series. Only part (less than half) of these wells were tubed. Guide, p. 450.

‖ Dr. Granville, letter to the *Times*, Aug. 23rd, 1850.

In the north of France generally the Tertiary strata bear a close resemblance to those of this country. In the neighbourhood of Paris they become more varied and are more difficult to bore through. The Chalk, Upper Greensand, and Gault, are almost identical with the same deposits here.

Works of small depth, and through the Tertiary series, appear to cost less in this country than in France. Even in wells partly dug (and steined) and partly bored, the expense is now comparatively moderate. Thus at the Colney Hatch Asylum we find that a shaft was dug to the depth of 144 feet, and then a bore carried to a further depth of 185 feet, at an expense, including steining and pumps, of 1,273*l.*; and at the New City Prison, at Holloway, a shaft 5 feet in diameter was sunk to the depth of 217 feet, and a bore of 10 inches then carried 102 feet into the chalk, for 1,300*l.*; while at Loughton, according to Dr. Mitchell, a depth of 535 feet was bored for about 750*l.*

Allowing therefore for the different value of labour and superintendence, there can be, I conceive, no reason why, in other respects, the greater depths should not be attained at nearly the same cost at London as on the continent. Estimating this difference, on data for which I am indebted to an English engineer who has resided several years in France, at about one third extra, and assuming that the *Upper Greensand* is at a depth of not more than 800 to 900 feet beneath London, then it should be reached by an Artesian boring at an expense certainly *not exceeding* 1,800*l.* to 2,500*l.* and in the same way the *Lower Greensand at about* 1,000*l.* more. (This last to allow for greater diameter of bore, as well as for increased depth.)

Considering the large dimensions, and the height above London of the outcrop of the *Lower Greensand* (consequently the velocity with which the water would issue from the bore-pipes), it seems to me perfectly possible to obtain from it at any given point, by means of a single Artesian well, 1¼

to 1½ million gallons of water daily, and from the *Upper Greensand*, ¾ to 1 million gallons. If, therefore, there were constructed, at certain distances, groups of three of such wells, of which two in the Lower, and one in the Upper Greensand—one of the former being kept in reserve, and the other two in constant use—each separate group would possibly yield 2 to 2½ million gallons of water daily. The construction of these groups might be continued in a circle around London, so long as the water-bearing strata yielded supplies which, after the equilibrium among the wells was established, should maintain a *permanent* value.* Should the anticipated results succeed so as to be able to increase the groups to the number of fifteen to twenty, without diminishing their respective efficiency, such a series might probably furnish to the Metropolis a supply of from 30,000,000 to 50,000,000 gallons of water daily, at an expense (for the wells only and the delivery taken at, or rather above the surface) in the ratio of the above mentioned probable cost of construction, *i. e.*, of from 100,000*l.* to 190,000*l.*

* To obtain this permanence an indiscriminate use of this source of supply is a danger indispensably to be provided against.

EXPLANATION OF MAP AND SECTIONS.

Map.

THE geographical outlines and river courses are an exact transfer from the larger (ten inches to the mile) Index Ordnance Map. The geological boundaries of the Tertiary series are reduced from my own observations, laid down on the ordinary Ordnance Map of one inch to the mile. As this map, therefore, bears a fixed relation to the Ordnance Map, the geological position of any other places than those given, can readily be determined, by reference from the larger Ordnance, to its reduced Index Map, and by transfer to this one.

The geological boundaries of the Upper and Lower Greensand are taken chiefly from Dr. Fitton's Map in the 4th Vol. 2nd. Ser. Trans. Geol. Soc., and from Mr. Greenough's Geological Map of England. I have introduced, however, a few alterations in the Cretaceous districts westward of Cambridge and Maidstone (see p. 75).

The superficial deposits of Drift and the Crag, are not represented.

On the chalk of Surrey there are a few detached Tertiary outliers, and a greater number in Berkshire, Buckinghamshire, and Hertford ; they are omitted in the Map. (see ¶ 20.)

The lines of disturbance are only laid down generally; they are rather too straight ; this however is only relative.

The main line of E. and W. disturbance, passing by Deptford and Windsor, forms, with the dotted line passing N. and S. up the valleys of the Ravensbourne and Lea, the boundaries of the four divisions under which the geological structure has been considered. The large outline capital initial letters mark the position of these divisions.

The figures on the Map indicate the approximate height of the country (following the course of the rivers, and necessarily therefore the lowest levels of the several districts) above high-water mark, Trinity Standard (1800) at the London Docks.* For the height of the zones of outcrop between these points see p. 144.

The greater number of the rivers and streams are laid down in order to show the bearing of the several geological formations on the superficial drainage.

The faint dotted lines mark the boundaries of counties.

Sections.

THE relative thickness of the different formations is given generally ; but the scale being small, the proportions are not quite exact.

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* In the reference to Trinity high-water level in the sections for "London Bridge" *read* "the London Docks."

The scale of depth to distance is as 6·3 to 1, for the purpose of showing more readily the main features of the phenomena. In looking at the dip of the strata this must be taken into account.

The figures mark the heights above Trinity high-water level at London.

In Section No. 1, the surface of the chalk between Highgate and Tooting is represented as rather too level; it should rise more towards both these places.

In Section No. 2, the points "*s*" show the position generally of the springs of the Bagshot Sands.

THE END.

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